AABMs inventory

Inventory of activity- and agent-based transport models

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Executive summary

Introduction

This report provides an inventory and analysis of activity- and agent-based models (AABMs). The reason for the inventory is that traditional models are often unable to calculate travel behaviour in detail, for example for studies on Quality of Life, target-group analysis and smart mobility solutions. Traditional models often do not or insufficiently calculate the effects of such mobility services and policies. The question is whether AABMs are better able to answer questions on these topics. The report answers this question. It is based on a literature review, interviews and a workshop, aiming to discuss diverse topics related to AABMs such as definitions, advantages and disadvantages.

Key findings from this report include that AABMs offer a more nuanced and accurate representation of travel behaviour and can thus better inform the effects of policy and infrastructure planning. Furthermore, this report highlights the importance of data, advanced computing resources and interdisciplinary collaboration in the development and application of these models. It discusses the challenges associated with the transition from traditional models to AABMs, including issues such as privacy, model complexity, investment needs, training, communication and organisation.

This report advocates the introduction of AABMs to improve the understanding of travel behaviour and provide more detailed input for planning and policy decision-making. The benefits of greater accuracy, more realistic behavioural effects and improved simulation capabilities make AABMs an important step forward in answering mobility issues. The study's findings are intended to inform diverse stakeholders and guide future efforts in transport modelling and mobility planning.

Background

In the Netherlands, the partnership SIVMO (Samenwerkingsverband en Innovatie Verkeersmodellen door Overheden) was set up to investigate developments in transport and traffic modelling. The changing mobility landscape has prompted SIVMO to explore more advanced modelling techniques, such as activity- and agent-based models. The changes in passenger transport and mobility are characterised by innovations such as Quality of Life, Mobility as a Service (MaaS), micro-mobility, smart mobility, car-sharing, e-commuting, and e-commerce. These developments are challenging the existing transport models as used by various Dutch government agencies. It requires rethinking models to better understand today's mobility patterns.

This study explores new transport modelling techniques (AABMs), which are said to be able to provide more detailed insights into human behaviour and the impact of policy changes. AABMs represent a potential successor to traditional models, driven mainly by the need for a more nuanced and detailed understanding of mobility dynamics and the integration of new transport services.

This report provides answers to several questions raised by SIVMO, including model implementation, model complexity, data privacy concerns and the overarching goal of defining, applying and understanding the benefits and limitations of these advanced modelling approaches. SIVMO's questions were answered through desk research (literature), interviews and a workshop.

Definitions

Understanding the distinction between activity- and agent-based models (AABMs)[1] is important for their use in transport planning and policy analysis. It is important to clearly define the terminology between activity-based models (AcBMs) and agent-based models (AgBMs), so that the methods chosen best fit the goals of transport planning and policy analysis.

Activity-based models (AcBMs) focus on the sequence and duration of activities performed by individuals and households during a day. , taking constraints and preferences of households and individuals into account. These models provide a detailed understanding of travel behaviour by considering the interconnectedness of different activities, leading to more accurate predictions of travel patterns.

Agent-based models (AgBMs) go beyond activity tracking. These models emphasise the interactions between agents (persons or vehicles) and their dynamics between them. AgBMs are suitable for determining the behaviour that arises from these interactions between different agents, such as in traffic congestion or the use of shared mobility services. These models are adaptive and can learn from changing conditions, enabling them to provide more accurate and realistic simulations. Self-learning is a key feature of these models.

The methodological distinction between AcBMs and AgBMs is important for their application. AcBMs predict transport demand by using detailed data on the activities of individuals and households. The term 'activity-based model' is well-defined and fits within the description of traditional methods such as ‘trip-based’ and ‘tour-based’ models. AgBMs, on the other hand, simulate the interactions between individual agents and emphasise the dynamics within the transport system. The use of the term 'agent-based model' is often ambiguous and open to multiple interpretations. It is also used for multiple components of transport models. In addition, (as far as we know) a self-learning agent-based model does not (yet) exist within the world of transport modelling.

The advice is therefore to avoid using the term 'agent-based model'. Instead, it is recommended to refer to specific underlying models such as population synthesis models, assignment models or activity planners.

[1] A glossary explaining different terms is provided on page 45.

Data

The success and reliability of AABMs depends on good data, careful data processing, expert use of the data, dealing with privacy concerns, and adapting to ever-changing data sources. To ensure that AABMs provide insightful and useful results for transport planning and policy analysis, it is important to consider these issues when developing AABMs. Although the following is drawn from the literature and interviews, the findings may also be applicable to traditional models. We provide these findings mainly to be comprehensive.

One of the key findings is the need for good surveys, integration of disparate data sources and continuous updating of datasets to incorporate changing behaviour. Processing these data presents challenges, such as ensuring representativeness and accuracy of the data. These are important for the final quality of model output. Big data offer additional insights into mobility patterns based on sources such as mobile phone data, GPS devices, social media platforms and floating car data.

The use of detailed data (from surveys) and big data (such as from public transport maps) can raise privacy concerns. The General Data Protection Regulation (GDPR, European Commission) requires that the use of data must ensure the anonymity and confidentiality of individuals. Changing data sources, driven by technological advances and changes in data generation and collection methods, presents both opportunities and challenges for model developers. In any case, the GDPR must be considered when developing models.

Methods

Several issues have been identified in developing and applying AABMs, such as the complexity of simulating human behaviour and resulting mobility, and integrating different data sources to develop representative models at urban, regional and national scales.

Solutions to these problems include the use of computing techniques such as parallel processing and cloud computing, which facilitate the processing of large data sets and complex simulations. On the other hand, model simplification and modularisation are being put forward as strategic approaches to manage complexity, facilitating incremental development, calibration and validation.

There are currently issues in AcBM that have not yet been adequately developed. Examples include dealing with stochasticity and implementing new techniques for population synthesis. For this, (existing) methods can be used, such as the use of semi-Monte Carlo simulations or 'seeds' in stochasticity and the use of machine learning in population syntheses. These methods are still being further developed and refined to better deal with these issues.

Dealing with stochasticity requires careful consideration because of the variability in simulation results, even with identical inputs. It is advisable to use 'seeds' or semi-Monte Carlo methods to guarantee reproducibility of results. For population synthesis, creating a national model is an important step that benefits all government agencies. The choice here between Iterative Proportional Fitting (IPF) and machine learning needs further deliberation. IPF provides a more accessible starting point for those who are new to population synthesis, but machine learning offers much wider opportunities to set up good and comprehensive population synthesis.

Policy

AABMs can be of great value in policy analysis, especially when used in passenger transport, urban planning and infrastructure development. They provide a better simulation of activities and the related travel behaviour of individuals. This provides policymakers and planners with a good basis for evaluating the potential effects of policy measures. It is particularly useful for understanding the behaviour of individuals in changes brought about by such measures. Altogether, it improves policy formulation that is not only effective, but also fair and sustainable. It contributes to the goal of improving mobility and quality of life.

AABMs can calculate a variety of policy questions. They offer richer and more detailed results compared to traditional models, to substantiate a variety of questions, such as:

- *Exploring social justice*. AABMs make it possible to explore how transport policies affect different population groups, including low-income households, the elderly or communities with limited access to transport alternatives. These models can reveal inequalities in access to employment, education or essential services so that policies can be developed that promote equity and inclusiveness.
- *Responding to new mobility trends*. As mobility evolves with trends such as shared mobility services, autonomous vehicles and micro-mobility solutions, AABMs are important to understand these changes. They provide insight into how these innovations may change travel behaviour, demand for different modes of transport and interaction with existing transport infrastructure. This provides more informed information for developing policies and infrastructure adaptations to integrate the new mobility options into the transport system.
- *Effects of transport pricing policies*. AABMs can examine in more detail how strategies such as congestion charges, parking charges or changes in public transport fares affect the behaviour of different user groups. Through simulations, these models can calculate shifts in transport mode choice, changes in vehicle kilometres travelled and changes in transport composition. Thus, they provide insight into the effects of pricing strategies on user groups and transport itself.
- *Evaluation of infrastructure investments*. Like traditional models, AABMs can assess the expected impacts of new transport infrastructure, such as road construction, expansion of the public transport network or creation of pedestrian-oriented urban areas. The models can predict changes in accessibility, redistribution of traffic flows and land-use impacts. The difference between AABMs and traditional models is that they can relate the impacts of investments in more detail to different user groups or times-of-day.
- *Assessment of technological innovations*. AABMs can examine the potential impacts of emerging transport technologies, such as autonomous vehicles or Mobility as a Service. By simulating the influences of these innovations on travel choices, policymakers can identify concerns and opportunities of technological developments.

- *Contribution to spatial planning and infrastructure development*. In spatial planning and infrastructure development, AABMs can serve as a tool to understand how changes in the built environment affect travel behaviour and community well-being. The detailed scenario analyses of AABMs help formulate policies that improve liveability, promote efficient land use and support the transition to a more sustainable and resilient environment.
- *Scenario analysis*. AABMs make it possible to examine different scenarios, such as higher population growth compared to the current forecast, or a decrease in employment due to a foreign political development. This allows us to simulate different population groups in each geographical area with special characteristics to understand their transport needs and the effects of new initiatives on each group. The AABM scenario analysis also allows us to quantify uncertainties in the model assumptions and external factors.

Process and organisation

The report also provides information on the processes, organisational frameworks, collaborative efforts and transition strategies for the development and implementation of AABMs. It highlights the need for an integrated approach that combines technical development, administrative preparations, and stakeholder engagement. The timeframe for creating a fully functional AABM can vary, with estimates between one and five years, depending on available resources, the level of preparation and procurement required, and the degree of innovation desired.

In building AABMs, the use of Agile methods is promoted. This is an approach where the project is divided into phases, with an emphasis on continuous improvement. Here, the focus is on creating viable products, while the model building processes are separated to properly manage the complexity of building models. It is important to think about the initial components to be built, such as a population synthesiser or activity planner. It is also important to involve stakeholders early in the process, for example by forming steering groups and providing clear communication.

In terms of engaging the market, several strategies are possible. These include partnerships, joint ownership, and/or collaborations between government agencies, academics and consultants. Best practices for organisation should be explored, such as the Alliance Freight Transport Models in the Netherlands. This involves a collaboration between government and market players to build, manage, expand, document and apply BasGoed, the national freight transport model. The main reason for cooperation is the limited knowledge base for AABMs in the Netherlands and the need to share knowledge between different organisations to provide a solid foundation for the development and application of AABMs.

The process and organisation approach not only supports the technical development of models, but also promotes a collaborative ecosystem needed for sustainable and efficient planning. In addition to SIVMO, the EABMA (European ABM Association, currently in formation) provides a good opportunity to connect with other partners across Europe.

Future developments

Future developments are likely to focus on further integration of the activity- and agent-based approaches. This integration should further combine the strengths to produce richer, more dynamic simulations of travel behaviour. Innovations in modelling techniques, driven by developments in big data, machine learning and artificial intelligence, are expected to further improve prediction accuracy and operational efficiency of transport models. A critical consideration, however, is to properly match the complexity of models with policy needs, so that they remain accessible and manageable for policymakers and practitioners.

In terms of data, the integration of big data and advanced methods such as machine learning into transport models is seen as a promising step forward. This does come with challenges in terms of data management, privacy protection and technical integration of different data sources. Improved data collection techniques enabled by digital and network technologies can provide richer, more detailed and real-time data on travel behaviour and the performance of transport systems. A limitation here is that big data is often less accessible due to privacy concerns, costs and market-sensitive information.

Advances in computing technologies, such as high-performance computing and cloud computing platforms, reduce current hardware limitations. This enables the development of more complex models over larger geographical areas and longer time horizons.

Advantages and disadvantages of AABMs

Advantages

AABMs offer several advantages over traditional transport models, mainly due to their ability to better describe human behaviour and interactions within a transport system. The advantages include:

- *Improved accuracy in predicting travel behaviour*. AABMs offer an advantage over traditional models when it comes to predicting travel behaviour more accurately. Traditional models are often based on aggregated data and simplified assumptions, which can lead to inaccuracies in representing complex travel patterns. For example, traditional models may struggle to simulate variability in daily travel decisions influenced by individual preferences and socio-economic factors such as income, age or education level. In contrast, AABMs consider detailed activity schedules and the interactions between different activities, providing a more accurate simulation of how people plan and execute their trips. This results in better predictions of travel times, route choices and transport mode preferences.
- *Better integration of new mobility trends.* AABMs are highly adaptable and can better incorporate the impact of new mobility trends such as Mobility as a Service (MaaS), autonomous vehicles and micro-mobility such as e-scooters and bike-sharing or public transport (OV) bikes. Traditional models often lack the flexibility to integrate these trends. For example, AABMs can simulate the shift from private

car use to shared mobility services in cities where MaaS is gaining popularity. This provides insight into the effect on congestion or parking demand, for example.

- *Improve capabilities for policy analysis.* Traditional models provide evaluations of policy effects but can overlook important nuances. AABMs make it possible to simulate the responses of (groups of) individuals and households to policy changes, providing a more detailed picture of the possible effects of measures. For example, an AABM can assess the effects of introducing congestion charges in a city, predicting not only the overall reduction in vehicle trips, but also specific groups most affected by the measure. This level of detail supports the development of more targeted and equitable policy interventions.
- *Interdisciplinary approach*. AABMs facilitate an interdisciplinary approach, integrating insights from psychology, sociology and urban planning to provide a more holistic view of the transport system. This integration helps to better understand not only the physical movement of people, but also the underlying social and psychological factors that influence their travel behaviour.
- *Analysis of different user groups.* The output of AABMs can be analysed for different groups of individuals. This allows evaluation of policies for equality and inclusion. This capability ensures that the needs and impacts on different demographic groups, such as low-income or elderly households, are included. It allows policymakers to assess how different policies affect various user groups to ensure that proposed transport solutions are inclusive and equitable.

Disadvantages

The disadvantages of AABMs should not go unmentioned. The main disadvantages from the literature, interviews and workshop:

- *Computational power.* AABMs require considerable computing power due to their detailed simulations of individual behaviour and interactions. This can result in longer computation times and potentially higher costs for model development and application. The use of advanced computing techniques such as parallel processing and cloud computing can help manage and control computational demands. Model simplification and modularisation can streamline processes and reduce computational burden without sacrificing accuracy. Looking at the current traditional models used in the Netherlands, computational power, computation times and computational costs are probably not a major problem.
- *Data needs*. AABMs need detailed data to function properly, including demographic information, activity calendars and transport networks. Collecting and maintaining such extensive datasets can be challenging and resource intensive. Data sharing agreements with various stakeholders and the use of big data sources such as mobile phone data and social media analytics can improve data availability. Regularly updating and validating data ensures that the model remains accurate and relevant. As traditional models in the Netherlands already have a large data requirement, this drawback is likely to be less of a concern. A significant part of the data (such as networks and socio-economic data) can be taken from traditional models.
- *Required skills.* Developing and using AABMs requires a high level of expertise in modelling and data analysis. This need for specialised skills can hinder the development and use of AABMs. To overcome this barrier, it is important to invest in training programmes for stakeholders, including government agencies, market players and academic institutions. Encouraging collaboration among these groups can also facilitate knowledge transfer and capacity building.

Advice and recommendations

The transition to AABMs in the Netherlands aims to improve the understanding of travel behaviour to support transport policy. Despite pioneering efforts in the 1990s, the application of advanced models in the Netherlands has stagnated. Current advances in both methodology and data, together with international momentum, underline the urgency for adopting activity-based models (AcBMs).

Key **technical steps** include **immediate action** for developing AcBMs, development and testing a **national population synthesis**, selecting a **pilot model**, enhancing **household travel surveys with home-based activities**, **incremental development**, controlling **stochastic outcomes**, using **open-source software** to avoid 'vendor lock-in', and **encouraging innovation**.

Organisational steps include setting up **training programmes** for stakeholders, forming an **AABM alliance** for joint development and application, **engaging diverse expertise** in model and software development, **collaborating with external stakeholders** to share data and best practices, **connecting with European partners** (EABMA), and **preparing policymakers** for the new modelling technique and its results.

Samenvatting

Inleiding

Dit rapport biedt een inventarisatie en analyse van activity- en agent-based modellen (AABM's). De reden voor de inventarisatie is dat traditionele modellen vaak niet in staat zijn om het reisgedrag tot in detail vast te berekenen, bijvoorbeeld voor studies op het gebied brede welvaart, doelgroepenanalyse en slimme mobiliteitsoplossingen. Traditionele modellen berekenen de effecten van dergelijke mobiliteitsdiensten en -maatregelen vaak niet of onvoldoende. De vraag is of AABM's beter in staat zijn om vragen over deze onderwerpen te beantwoorden. Het rapport geeft hierop antwoord. Het is gebaseerd op een literatuurstudie, interviews en een workshop, met als doel om uiteenlopende onderwerpen in relatie tot AABMs te bespreken zoals definities en voor- en nadelen.

De belangrijkste bevindingen uit dit rapport zijn onder meer dat AABMs een meer genuanceerde en accurate weergave van reisgedrag bieden en daarmee de effecten van beleid en infrastructuurplanning beter kunnen onderbouwen. Verder benadrukt dit rapport het belang van gegevens, geavanceerde computermiddelen en interdisciplinaire samenwerking bij de ontwikkeling en toepassing van deze modellen. Het bespreekt de uitdagingen die gepaard gaan met de overgang van traditionele modellen naar AABM's, waaronder onderwerpen zoals privacy, de complexiteit van de modellen, de behoefte aan investeringen, opleiding, communicatie en organisatie.

Dit rapport pleit voor de introductie van AABM's om het begrip van reisgedrag te verbeteren en meer gedetailleerde input te leveren voor de besluitvorming van planning en beleid. De voordelen van meer nauwkeurigheid, realistischer gedragseffecten en verbeterde simulatiemogelijkheden maken dat de AABM's een belangrijke stap voorwaarts zijn bij beantwoorden van mobiliteitsvraagstukken. De bevindingen van het onderzoek zijn bedoeld om uiteenlopende belanghebbenden te informeren en om richting te geven aan toekomstige inspanningen op het gebied van transportmodellering en mobiliteitsplanning.

Achtergrond

In Nederland is het samenwerkingsverband SIVMO (Samenwerkingsverband en Innovatie Verkeersmodellen door Overheden) opgericht om de ontwikkelingen op het gebied van vervoers- en verkeersmodellering te onderzoeken. Het veranderende mobiliteitslandschap heeft SIVMO ertoe aangezet om meer geavanceerde modelleringstechnieken te onderzoeken, zoals activity- en agent-based modellen. De veranderingen in personenvervoer en mobiliteit worden gekenmerk door innovaties zoals Mobility as a Service (MaaS), micro-mobiliteit, smart mobility, car-sharing, e-commuting, en e-commerce. Deze ontwikkelingen vormen een uitdaging voor de bestaande transportmodellen zoals die worden gebruikt door verschillende Nederlandse overheidsinstanties. Het vereist een heroverweging van de modellen om de hedendaagse mobiliteitspatronen beter te inzichtelijk te maken.

Deze studie verkent nieuwe technieken voor transportmodellering (AABMs), waarvan wordt gezegd dat ze gedetailleerdere inzichten kunnen verschaffen in menselijk gedrag en de impact van beleidsveranderingen. De AABM's vormen een potentiële opvolger van de traditionele modellen, vooral ingegeven door de behoefte aan een meer genuanceerd en gedetailleerd begrip van de mobiliteitsdynamiek en de integratie van nieuwe vervoersdiensten.

Dit rapport geeft antwoord op verschillende vragen die door SIVMO aan de orde zijn gesteld, zoals de implementatie van het model, de complexiteit van het model, zorgen over gegevensprivacy en het overkoepelende doel om de voordelen en beperkingen van deze geavanceerde modelbenaderingen te definiëren, toe te passen en te begrijpen. De vragen van SIVMO zijn beantwoord door middel van deskresearch (literatuur), interviews en een workshop.

Definities

Inzicht in het onderscheid tussen activity- en agent-based modellen (AABM's) is belangrijk voor het gebruik ervan in transportplanning en beleidsanalyse. Het is belangrijk om de terminologie tussen activity-based modellen (AcBM's) en agent-based modellen (AgBM's) duidelijk te definiëren, zodat de gekozen methoden zo goed mogelijk aansluiten bij de doelen van transportplanning en beleidsanalyse.

Activity-based modellen (AcBM's) richten zich op de opeenvolging en duur van activiteiten die individuen en huishoudens gedurende een dag uitvoeren, waarbij beperkingen en voorkeuren van individuen en huishoudens worden meegenomen. Deze modellen geven een gedetailleerd inzicht in het verplaatsingsgedrag, door rekening te houden met de onderlinge verbondenheid van verschillende activiteiten, wat leidt tot nauwkeurigere voorspellingen van verplaatsingspatronen.

Agent-based modellen (AgBM's) gaan verder dan het volgen van activiteiten. Deze modellen leggen de nadruk op de interacties tussen agenten (personen of voertuigen) en hun onderlinge dynamiek. AgBM's zijn geschikt voor het bepalen van het gedrag dat ontstaat uit deze interacties tussen verschillende agenten, zoals bij verkeersopstoppingen of het gebruik van gedeelde mobiliteitsdiensten. Deze modellen zijn adaptief en kunnen leren van veranderende omstandigheden, waardoor ze in staat zijn om nauwkeurigere en realistischere simulaties te bieden. Het zelflerende karakter is een essentiële eigenschap van deze modellen.

Het methodologische onderscheid tussen AcBM's en AgBM's is belangrijk voor hun toepassing. AcBM's voorspellen de vervoersvraag door gebruik te maken van gedetailleerde gegevens over de activiteiten van individuen en huishoudens. De term 'activity-based model' is goed afgebakend en past bij de beschrijving van de traditionele methoden zoals 'trip-based' en 'tour-based' modellen. AgBM's simuleren daarentegen de interacties tussen individuele agenten en leggen de nadruk op de dynamiek binnen het transportsysteem. Het gebruik van de term 'agent-based model' is vaak dubbelzinnig en voor meerdere uitleg vatbaar. Het wordt ook voor meerdere onderdelen van transportmodellen gehanteerd. Daarnaast bestaat (voor zover we weten) een zelflerend 'agent-based model' (nog) niet binnen de wereld van transportmodellen.

Het advies is daarom om het gebruik van de term ‘agent-based model’ te vermijden. In plaats daarvan wordt aanbevolen om te verwijzen naar specifieke onderliggende modellen zoals populatiesynthesemodellen, toedelingsmodellen of activiteitenplanners.

Gegevens

Het succes en de betrouwbaarheid van AABM's hangt af van goede data, zorgvuldige dataverwerking, deskundig gebruik van de data, het omgaan met de zorgen over privacy, en de aanpassing aan de steeds veranderende gegevensbronnen. Om ervoor te zorgen dat AABM's inzichtelijke en bruikbare resultaten opleveren voor transportplanning en beleidsanalyse, is het belangrijk om deze onderwerpen mee te nemen bij de ontwikkeling van AABM’s. Hoewel het onderstaande is ontleend aan de literatuur en de interviews, kunnen de bevindingen ook van toepassing zijn op traditionele modellen. We geven deze bevindingen vooral om volledig te zijn.

Eén van de belangrijkste bevindingen is de behoefte aan goede enquêtes, de integratie van ongelijksoortige gegevensbronnen en het voortdurend bijwerken van datasets om veranderend gedrag mee te nemen. De verwerking van deze gegevens brengt uitdagingen met zich mee, zoals het waarborgen van de representativiteit en de nauwkeurigheid van de gegevens. Deze zijn belangrijk voor de uiteindelijke kwaliteit van de modeluitvoer. Big data bieden aanvullende inzichten in mobiliteitspatronen op basis van bronnen zoals mobiele telefoongegevens, GPS-apparaten, sociale mediaplatforms en floating car data.

Het gebruik van gedetailleerde gegevens (uit enquêtes) en big data (zoals van openbaarvervoerkaarten) kan privacy problemen met zich meebrengen. De General Data Protection Regulation (GDPR, Europese Commissie) schrijft voor dat het gebruik van gegevens de anonimiteit en vertrouwelijkheid van individuen moet waarborgen. De veranderende gegevensbronnen, aangedreven door technologische vooruitgang en veranderingen in de methoden voor het genereren en verzamelen van gegevens, biedt zowel kansen als uitdagingen voor modelontwikkelaars. Bij het ontwikkelen van modellen moet in elk geval rekening worden gehouden met de GDPR.

Methoden

Bij het ontwikkelen en toepassen van AABM’s zijn verschillende vraagstukken geïdentificeerd, zoals de complexiteit van het simuleren van menselijk gedrag en de resulterende mobiliteit, en het integreren van verschillende gegevensbronnen om representatieve modellen op stedelijke, regionale en nationale schaal te ontwikkelen.

Oplossingen voor deze problemen zijn onder andere te vinden in het gebruik van computertechnieken zoals parallel processing en cloud computing, die de verwerking van grote datasets en complexe simulaties vergemakkelijken. Anderzijds worden modelvereenvoudiging en modularisering naar voren geschoven als strategische benaderingen om de complexiteit te beheersen, waardoor incrementele ontwikkeling, kalibratie en validatie wordt vereenvoudigd.

Momenteel spelen er vraagstukken bij AcBM die nog niet afdoende zijn uitgekristalliseerd. Voorbeelden zijn het omgaan met stochasticiteit en het implementeren van nieuwe technieken voor populatiesynthese. Daarvoor kunnen (bestaande) methoden worden ingezet, zoals het gebruik van semi-Monte Carlo simulaties of ‘seeds’ [2] bij stochasticiteit en het gebruik van machine learning bij populatie syntheses. Deze methoden worden nog steeds doorontwikkeld en verfijnd om beter met deze vraagstukken om te gaan.

Omgaan met stochasticiteit vereist een zorgvuldige overweging vanwege de variabiliteit in simulatieresultaten, zelfs met identieke invoer. Het is raadzaam om 'seeds' of semi-Monte Carlo methoden te gebruiken om de reproduceerbaarheid van resultaten te garanderen. Voor de populatiesynthese is het creëren van een landelijk model een belangrijke stap die alle overheidsinstanties ten goede komt. De keuze hierbij tussen Iterative Proportional Fitting (IPF) en machine learning heeft verdere aandacht nodig. IPF vormt een toegankelijker startpunt voor degenen die nieuw zijn in de populatie synthese, maar machine learning biedt veel ruimere mogelijkheden om goede en uitgebreide populatie synthese op te zetten.

Beleid

AABM's kunnen van grote waarde zijn in beleidsanalyses, vooral bij het gebruik in personenvervoer, stedelijke planning en infrastructuurontwikkeling. Ze bieden een betere simulatie van activiteiten en het daarmee samenhangende reisgedrag van individuen. Dit biedt beleidsmakers en planners een goede basis voor het evalueren van de potentiële effecten van beleidsmaatregelen. Het is vooral nuttig voor het begrijpen van het gedrag van individuen bij veranderingen die dergelijke maatregelen met zich meebrengen. Alles bij elkaar verbetert het de formulering van beleid, dat niet alleen effectief is, maar ook eerlijk en duurzaam. Het draagt bij aan het doel om de mobiliteit en brede welvaart te verbeteren.

AABM's kunnen verschillende beleidsvragen doorrekenen. AABM’s bieden rijkere en meer gedetailleerde resultaten in vergelijking met de traditionele modellen, om uiteenlopende vragen te onderbouwen, zoals:

- *Verkenning van sociale rechtvaardigheid*. AABM's maken het mogelijk om te onderzoeken hoe vervoersbeleid verschillende bevolkingsgroepen beïnvloedt, waaronder huishoudens met een laag inkomen, ouderen of gemeenschappen met beperkte toegang tot vervoersalternatieven. Deze modellen kunnen ongelijkheden blootleggen in de toegang tot werkgelegenheid, onderwijs of essentiële diensten, zodat beleid kan worden ontwikkeld dat gelijkheid en inclusiviteit bevordert.
- *Inspelen op nieuwe mobiliteitstrends*. Naarmate mobiliteit evolueert met trends zoals gedeelde mobiliteitsdiensten, autonome voertuigen en micromobiliteits-oplossingen, zijn AABM's belangrijk om deze veranderingen te begrijpen. Ze bieden inzicht in hoe deze innovaties het reisgedrag, de vraag naar verschillende vervoerswijzen en de interactie met de bestaande vervoersinfrastructuur kunnen veranderen. Dit geeft meer onderbouwde informatie voor de ontwikkeling van

[2] Zie pagina 45 voor uitleg van de gehanteerde begrippen.

beleid en infrastructuuraanpassingen om de nieuwe mobiliteitsopties te integreren in het transportsysteem.

- *Effecten van prijsbeleid voor vervoer*. AABM's kunnen gedetailleerder onderzoeken hoe strategieën zoals congestieheffingen, parkeertarieven of wijzigingen in de tarieven van het openbaar vervoer het gedrag van verschillende gebruikers-groepen beïnvloeden. Via simulaties kunnen deze modellen verschuivingen in de vervoerswijzekeuze, veranderingen in het aantal afgelegde voertuigkilometers en veranderingen in de vervoerssamenstelling berekenen. Zo geven ze inzicht in de effecten van prijsstrategieën op bepaalde gebruikersgroepen en het vervoer zelf.
- *Evaluatie van infrastructuurinvesteringen*. Net als traditionele modellen kunnen AABM's de verwachte effecten van nieuwe transportinfrastructuur beoordelen, zoals de aanleg van wegen, de uitbreiding van het openbaarvervoernetwerk of het creëren van voetgangersgeoriënteerde stedelijke gebieden. De modellen kunnen veranderingen in de bereikbaarheid, de herverdeling van verkeersstromen en de gevolgen voor het landgebruik voorspellen. Het verschil tussen AABM's en traditionele modellen is dat ze de gevolgen van de investeringen in meer detail kunnen relateren aan verschillende gebruikersgroepen.
- *Beoordeling van technologische innovaties*. AABM's kunnen de potentiële effecten van opkomende vervoerstechnologieën onderzoeken, zoals autonome voertuigen of Mobility as a Service. Door de invloeden van deze innovaties op reiskeuzes te simuleren, kunnen beleidsmakers de aandachtspunten en kansen van technologische ontwikkelingen identificeren.
- *Bijdrage aan ruimtelijke ordening en infrastructuurontwikkeling*. Bij ruimtelijke ordening en infrastructuurontwikkeling kunnen AABM's als hulpmiddel dienen om te begrijpen hoe veranderingen in de gebouwde omgeving het reisgedrag en het welzijn van de gemeenschap beïnvloeden. De gedetailleerde scenarioanalyses van AABM's helpen bij het formuleren van beleid dat de leefbaarheid verbetert, efficiënt landgebruik bevordert en de transitie naar een duurzamere en veerkrachtigere omgeving ondersteunt.
- *Scenario-analyse*. AABM's maken het mogelijk om verschillende scenario's te onderzoeken, zoals een hogere bevolkingsgroei ten opzichte van de huidige verwachting, of een daling van de werkgelegenheid als gevolg van een buitenlandse politieke ontwikkelingen. Dit stelt ons in staat om verschillende bevolkingsgroepen in elk geografisch gebied met speciale kenmerken te simuleren om inzicht te krijgen in hun vervoersbehoeften en de effecten van nieuwe initiatieven op elke groep. De AABM-scenario-analyse biedt ook de mogelijkheid om onzekerheden in de modelaannames en externe factoren te kwantificeren.

Proces en organisatie

Het rapport biedt ook informatie over de processen, organisatorische kaders, samenwerkingsinspanningen en transitiestrategieën voor de ontwikkeling en implementatie van AABM's. Het benadrukt de noodzaak van een geïntegreerde aanpak die technische ontwikkeling, administratieve voorbereidingen, en betrokkenheid van belanghebbenden combineert. Het tijdsbestek voor het creëren van een volledig functioneel AABM kan variëren, met schattingen tussen één en vijf jaar, afhankelijk van de beschikbare middelen, het vereiste niveau van voorbereiding en aanbesteding, en de gewenste mate van innovatie.

Bij de bouw van AABM's wordt het gebruik van Agile-methoden gepromoot. Dit is een aanpak waarbij het project in fasen wordt opgedeeld, met nadruk op continue verbetering. Hierbij ligt de focus op het creëren van levensvatbare producten, terwijl de modelbouwprocessen worden gescheiden om de complexiteit van de bouw van modellen goed te beheren. Het is belangrijk om na te denken over de eerste componenten die gebouwd moeten worden, zoals een populatiesynthesizer of activiteitenplanner. Daarnaast is het belangrijk om belanghebbenden vroeg in het proces te betrekken, bijvoorbeeld door het vormen van stuurgroepen en het verzorgen van duidelijke communicatie.

Wat betreft het betrekken van de markt, zijn er meerdere strategieën mogelijk. Deze bestaan uit partnerschappen, gezamenlijk eigenaarschap, en/of samenwerkingsverbanden tussen overheidsinstanties, academici en consultants. Best practices voor de organisatie moeten worden onderzocht, zoals de Alliantie Goederenvervoermodellen in Nederland. Hierbij is een samenwerking tussen overheid en marktpartijen aangegaan voor de bouw, beheer, uitbreiding, documentatie en toepassing van BasGoed, het nationale goederenvervoermodel. De belangrijkste reden voor samenwerking is de beperkte kennisbasis voor AABM's in Nederland en de noodzaak om kennis te delen tussen verschillende organisaties om zo een stevige basis te leggen voor de ontwikkeling en toepassing van AABM's.

De aanpak voor proces en organisatie ondersteunt niet alleen de technische ontwikkeling van modellen, maar bevordert ook een samenwerkend ecosysteem dat nodig is voor een duurzame en efficiënte planning. Naast SIVMO biedt de EABMA (European ABM Association, momenteel in oprichting) een goede gelegenheid om in contact te komen met andere partners in heel Europa.

Toekomstige ontwikkelingen

De toekomstige ontwikkelingen richten zich waarschijnlijk op een verdere integratie van de activity- en agent-based benaderingen. Deze integratie moet de sterke punten van beide verder combineren om rijkere, dynamischere simulaties van reisgedrag te produceren. Innovaties in modeltechnieken, aangedreven door ontwikkelingen in big data, machine learning en kunstmatige intelligentie, zullen naar verwachting de nauwkeurigheid van voorspellingen en de operationele efficiëntie van vervoersmodellen verder verbeteren. Een kritische overweging is wel om de complexiteit van modellen goed af te stemmen op de beleidsbehoeften, zodat ze toegankelijk en hanteerbaar blijven voor beleidsmakers en praktijkmensen.

Wat gegevens betreft, wordt de integratie van big data en geavanceerde methoden zoals machine learning in vervoersmodellen gezien als een veelbelovende stap voorwaarts. Dit gaat wel gepaard met uitdagingen op het gebied van gegevensbeheer, privacybescherming en technische integratie van verschillende gegevensbronnen. Verbeterde technieken voor gegevensverzameling, mogelijk gemaakt door digitale en netwerktechnologie, kunnen rijkere, meer gedetailleerde en realtime gegevens opleveren over reisgedrag en de prestaties van vervoerssystemen. Een beperking hierbij is dat big data vaak minder toegankelijk is vanwege privacyoverwegingen, kosten en marktgevoelige informatie.

Vooruitgang op het gebied van computertechnologieën, zoals high-performance computing en cloud computing platforms, verminderen de huidige beperkingen op het gebied van hardware. Dit maakt de ontwikkeling van complexere modellen over grotere geografische gebieden en langere tijdshorizonten mogelijk.

Voor- en nadelen van AABM's

Voordelen

AABM's bieden verschillende voordelen ten opzichte van traditionele transport-modellen, vooral door hun vermogen om het menselijk gedrag en interacties binnen een transportsysteem beter te beschrijven. De voordelen zijn onder meer:

- *Verbeterde nauwkeurigheid in het voorspellen van verplaatsingsgedrag*. AABM's bieden een voordeel ten opzichte van traditionele modellen als het gaat om het nauwkeuriger voorspellen van reisgedrag. Traditionele modellen zijn vaak gebaseerd op geaggregeerde gegevens en vereenvoudigde aannames, wat kan leiden tot onnauwkeurigheden bij het weergeven van complexe reispatronen. Traditionele modellen kunnen bijvoorbeeld moeite hebben met het simuleren van de variabiliteit in dagelijkse reisbeslissingen die worden beïnvloed door individuele voorkeuren en sociaaleconomische factoren zoals inkomen, leeftijd of opleidingsniveau. AABM's daarentegen houden rekening met gedetailleerde activiteitenschema's en de interacties tussen verschillende activiteiten, waardoor een nauwkeurigere simulatie ontstaat van hoe mensen hun reizen plannen en uitvoeren. Dit resulteert in betere voorspellingen van reistijden, routekeuzes en vervoerwijze voorkeuren.
- *Betere integratie van nieuwe mobiliteitstrends.* AABM's zijn goed aan te passen en kunnen de impact van nieuwe mobiliteitstrends zoals Mobility as a Service (MaaS), autonome voertuigen en micro-mobiliteit zoals e-scooters en fietsdelen of OV-fiets beter meenemen. Traditionele modellen missen vaak de flexibiliteit om deze trends te integreren. AABM's kunnen bijvoorbeeld de verschuiving simuleren van het gebruik van privéauto's naar gedeelde mobiliteitsdiensten in steden waar MaaS aan populariteit wint. Dit geeft bijvoorbeeld inzicht in het effect op congestie of de vraag naar parkeerplaatsen.
- *Mogelijkheden voor beleidsanalyse verbeteren.* Traditionele modellen bieden evaluaties van beleidseffecten, maar kunnen belangrijke nuances over het hoofd zien. AABM's maken het mogelijk om de reacties van (groepen van) individuen en huishoudens op beleidsveranderingen te simuleren, waardoor een meer gedetailleerd beeld ontstaat van de mogelijke effecten van maatregelen. Een AABM kan bijvoorbeeld de effecten van de invoering van congestieheffingen in een stad beoordelen, waarbij niet alleen de algehele vermindering van het aantal voertuigritten wordt voorspeld, maar ook specifieke groepen die het meest door de maatregel worden getroffen. Dit detailniveau ondersteunt de ontwikkeling van meer gerichte en rechtvaardige beleidsinterventies.
- *Interdisciplinaire aanpak*. AABM's faciliteren een interdisciplinaire aanpak, waarbij inzichten uit de psychologie, sociologie en stedenbouw worden geïntegreerd om een meer holistische kijk op het transportsysteem te bieden. Deze integratie helpt om niet alleen de fysieke verplaatsing van mensen beter te begrijpen, maar ook de onderliggende sociale en psychologische factoren die hun reisgedrag beïnvloeden.

- *Analyse van verschillende gebruikersgroepen.* De output van AABM's kan worden geanalyseerd voor verschillende groepen van individuen. Hiermee kunnen beleidsmaatregelen voor gelijkheid en inclusie worden geëvalueerd. Deze mogelijkheid zorgt ervoor dat de behoeften en gevolgen voor verschillende demografische groepen, zoals huishoudens met een laag inkomen of ouderen, worden meegenomen. Het stelt beleidsmakers in staat om te beoordelen hoe verschillend beleid diverse gebruikersgroepen beïnvloedt, zodat de voorgestelde vervoersoplossingen inclusief en rechtvaardig zijn.

Nadelen

De nadelen van AABM’s mogen niet onbenoemd blijven. De belangrijkste nadelen uit de literatuur, interviews en workshop:

- *Rekenkracht.* AABM's vereisen aanzienlijke rekenkracht vanwege hun gedetailleerde simulaties van individueel gedrag en interacties. Dit kan resulteren in langere rekentijden en mogelijk hogere kosten voor modelontwikkeling en -toepassing. Het gebruik van geavanceerde computertechnieken zoals parallelle verwerking en cloud computing kan helpen bij het beheren en beheersen van de rekeneisen. Modelvereenvoudiging en modularisering kunnen de processen stroomlijnen en de rekenlast verminderen zonder dat dit ten koste gaat van de nauwkeurigheid. Kijkend naar de huidige traditionele modellen die in Nederland worden gebruikt, vormen rekenkracht, rekentijden en rekenkosten waarschijnlijk geen groot probleem.
- *Gegevensbehoeften*. AABM's hebben gedetailleerde gegevens nodig om goed te kunnen functioneren, waaronder demografische informatie, activiteitenagenda's en transportnetwerken. Het verzamelen en onderhouden van dergelijke uitgebreide datasets kan een uitdaging zijn en veel middelen vergen. Overeenkomsten voor het delen van gegevens met verschillende belanghebbenden en het gebruik van "big data"-bronnen zoals mobiele telefoongegevens en analyses van sociale media kunnen de beschikbaarheid van gegevens verbeteren. Het regelmatig bijwerken en valideren van gegevens zorgt ervoor dat het model accuraat en relevant blijft. Omdat de traditionele modellen in Nederland al een grote gegevensbehoefte kennen, zal dit nadeel waarschijnlijk minder zwaar wegen. Een belangrijk deel van de data (zoals netwerken en sociaaleconomische data) kan uit de traditionele modellen worden overgenomen.
- *Vereiste vaardigheden.* Het ontwikkelen en gebruiken van AABM's vereist een hoog niveau van expertise in modellering en gegevensanalyse. Deze behoefte aan gespecialiseerde vaardigheden kan de ontwikkelinge en toepassing van AABM’s in de weg staan. Om deze barrière te overwinnen, is het belangrijk om te investeren in opleidingsprogramma's voor belanghebbenden, waaronder overheidsinstanties, marktspelers en academische instellingen. Het aanmoedigen van samenwerking tussen deze groepen kan ook kennisoverdracht en capaciteitsopbouw vergemakkelijken.

Advies en aanbevelingen

De overgang naar AABM’s in Nederland heeft als doel het inzicht in reisgedrag te verbeteren en zo het vervoersbeleid te ondersteunen. Ondanks baanbrekende inspanningen in de jaren 1990, is de toepassing van geavanceerde modellen in Nederland gestagneerd. De huidige vooruitgang in zowel methodologie als data, samen met een internationaal momentum, onderstrepen de urgentie voor het invoeren van activity-based modellen (AcBM's).

De belangrijkste **technische stappen** omvatten **onmiddellijke actie** voor de ontwikkeling van AcBM's, het **opzetten en toetsen van een nationale populatiesynthese**, het selecteren van een **pilotmodel**, het **uitbreiden van de huishoud-reisonderzoeken met activiteiten** die thuis worden ontplooid, een **incrementele ontwikkeling**, het **beheersen van stochastische uitkomsten**, het gebruik van **open source software** om een ‘vendor lock-in’ te voorkomen, en om innovatie aan te moedigen.

Organisatorische stappen omvatten het opzetten van **trainingsprogramma's** voor belanghebbenden, het vormen van een **AABM-alliantie** voor gezamenlijke ontwikkeling en toepassing, het **betrekken van diverse expertise** bij model- en softwareontwikkeling, **samenwerking met externe belanghebbenden** voor het delen van gegevens en best practices, **aansluiting zoeken bij Europese partners** (EABMA), en het **voorbereiden van beleidsmakers** op de nieuwe modelleringstechniek en de resultaten ervan.


1

1 Introduction

The SIVMO[3] partnership explores advanced transport modelling techniques in response to changing mobility trends in the Netherlands. This chapter provides the background, objectives, and report structure.

1.1 Background and objectives

We are currently seeing several transformations in the field of passenger transport and mobility. These include concepts such as Quality of Life, Mobility as a Service (MaaS), micro-mobility, smart mobility, car-sharing, e-commuting, and e-commerce. These developments pose many challenges to the existing transport models of various government agencies in the Netherlands. Therefore, these agencies have collaborated to determine the best course of action for transport modelling.

The SIVMO partnership was set up to investigate advances in transport modelling. The changing mobility landscape has prompted SIVMO to explore more advanced modelling techniques, such as activity- and agent-based models. Although traditional models have proven their effectiveness, they sometimes fail to adequately capture the complexity of human behaviour and environmental influences. Activity- and agent-based models are considered potential replacements for conventional trip- or tour-based models and offer deeper insights into human behaviour, the effects of comprehensive policy changes and emerging services such as car-sharing, MaaS and e-commute.

However, the application and implementation of activity- and agent-based models presents challenges for government agencies. They have questions about definitions, data requirements, pros and cons and experiences with these models. Moreover, concerns remain about data privacy, data availability and the complexity of the models. The SIVMO partnership is therefore dedicated to exploring and defining the potential, challenges, and uses of activity- and agent-based models in the mobility sector.

The aim of this study is to address several issues facing SIVMO regarding activity- and agent-based models (AABMs). The basis of this report consists of desk research, interviews with government agencies, consultants and academic experts, and a workshop. The key questions underlying this report are described in chapter 3.

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[3] SIVMO stands for 'Samenwerkingsverband en Innovatie Verkeersmodellen door Overheden' (Collaboration and Innovation of Traffic Models by Governments). SIVMO comprises of Rijkswaterstaat, ProRail, Province of Noord-Brabant, Province of Utrecht, Vervoersregio Amsterdam, Metropolitan Region of Rotterdam and The Hague, and the municipalities of Amsterdam, Rotterdam, The Hague, and Utrecht.

1.2 Relation to other SIVMO projects

This AABMs inventory is among the initiatives that SIVMO started in 2023. Other projects launched by SIVMO in 2023 include:

1 *Principles and definitions*. The objective of this project is to harmonise definitions and assumptions used in traffic and transportation analyses across different authorities. The goals include investigating definitions and sources for model variables, understanding the scenarios used by partners, and advising on scenario selection for forecast calculations.

2 *Better modelling of innovations and new policy instruments*. The aim of this project is to enhance traffic models to effectively simulate new developments and policy tools. The project focuses on defining, designing, and testing new modelling approaches as well as the generation of additional output for policy indicators and compiling existing knowledge on the topic.

3 *State-of-the-art modelling of human behaviour*. The purpose of this project is to Improve the representation of human behaviour in traffic and transportation models. The project tries to identify key behavioural factors influencing mobility and determines the necessary data and efforts to model these behaviours accurately.

4 *Agent & activity-based modelling (AABM).* The goal of this project is to develop an AABM framework for the Dutch context. The objectives include defining AABM, inventorying required data, and assessing the advantages and practical experiences of AABM implementations by other governments.

The current report refers to action point 4.

In 2024, SIVMO plans to launch additional projects, with the intention of continuing these efforts in the coming years. These projects are intended to produce recommendations for improving the current transport models. Also, they may lead to new products or implementation in existing models. It is conceivable that some recommendations will point to the need for more detailed modelling of individual behaviour, or the desire to generate output for specific focus groups to evaluate new policies. In traditional transport demand models, such undertakings would be almost impossible. While disaggregated models can meet these needs to some extent, they lack the flexibility that an AABM provides. An AABM seems to be the most adaptable model currently available, but this needs to have more attention, as there are still several questions on topics such as the concept, definitions, methods, data, policy measures, and organisation of AABMs.

1.3 Structure of the report

This report comprises a brief overview of the questions and answers, as well as the advice and recommendations. The main part of the report consists of annexes in which the findings from the literature, interviews and workshop are described. For those who would like to see more background information, it is recommended to read annexes 3 (findings from literature), 4 (findings from interviews and 6 (findings from the workshop). A glossary is added to explain some of the modelling terms in this report.

This main part of the report is brief and structured as follows:

- Chapter 2 outlines a vision on transport models in general.
- Chapter 3 provides responses to all the posed questions.
- Chapter 4 offers recommendations and advice.

The annexes provide a wealth of information, collected from literature, interviews and a workshop. For each, notes are provided as well as a summary of findings in the following annexes:

- Annex 1 provides an overview of the literature collected. These include books, articles, reports, papers, and presentations. From this list, 30 documents were studied in more detail.
- Annex 2 offers insights in the selection of 30 documents from the collected literature.
- Annex 3 presents a summary of the findings from the literature review.
- Annex 4 provides the findings from the interviews.
- Annex 5 contains notes from the interviews, involving discussions with 22 experts, government officials, and consultants.
- Annex 6 summarises the results of the workshop.

Note: This report has been drafted using different software tools. These tools comprise Whisper, Deepl, ChatGPT, Google Scholar, ResearchGate, and Elicit. These tools helped us in carrying out the desk research, interviews, workshop, and drafting the final report itself.


2

2 Vision on transport models

What is a transport model? How is it related to an activity-based model? What other types of models exist? What are the key definitions to distinguish between the different types of models? This chapter introduces the topic of the inventory by providing a general overview of the transport model and the role of activity-based models.

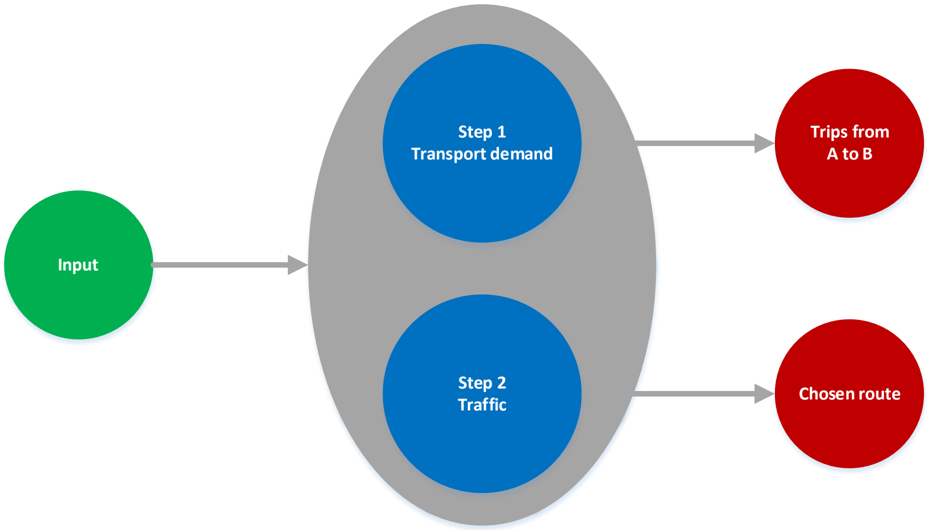
2.1 The 2-step model

For many users, transport models are a black box. These models are relied on, to provide relevant and useful data for policymaking. The task of assessing the quality of model results is reserved for specialists. A better understanding of these models can reduce the perception that they are not transparent. It is not mandatory to exhaustively understand the details of a model. Even a rudimentary understanding provides a basic appreciation of how a transport model works.

When clarifying a model, it is necessary to focus on the users of the model's results rather than the experts themselves. Experts often refer to transport models using a four-step model that successively includes sub-models for production/attraction, distribution, mode choice and assignment. The new sub-models such as time-of-day choice have made the four-step paradigm obsolete. Moreover, the emergence of tour- or activity-based models has invalidated the traditional four-step paradigm concept. Such developments do not make understanding these models any easier. Therefore, a simple methodology is proposed to improve the general understanding of transport models.

To this end, a fundamental concept underlying all transport models is introduced: the principle of the two-step model. The following diagram illustrates this concept, where a transport model essentially generates the transport demand (usually represented in an origin-destination tables) and the traffic flow (usually represented in loaded networks). This includes the volume of individuals travelling from location A to location B and the routes they choose. The origin-destination tables are generated through a transport demand (or transportation) model and the loaded networks through a traffic (or assignment) model. The exact mechanisms of these models are not discussed for brevity.

Figuur 1 Two-step transport model



Source: Panteia

2.2 Further detailing the 2-step model

The 2-step model is structured into a linked transport demand model (or a transportation model) and a traffic model (or an assignment model)[4]. Both types can be further distinguished into different types of models.

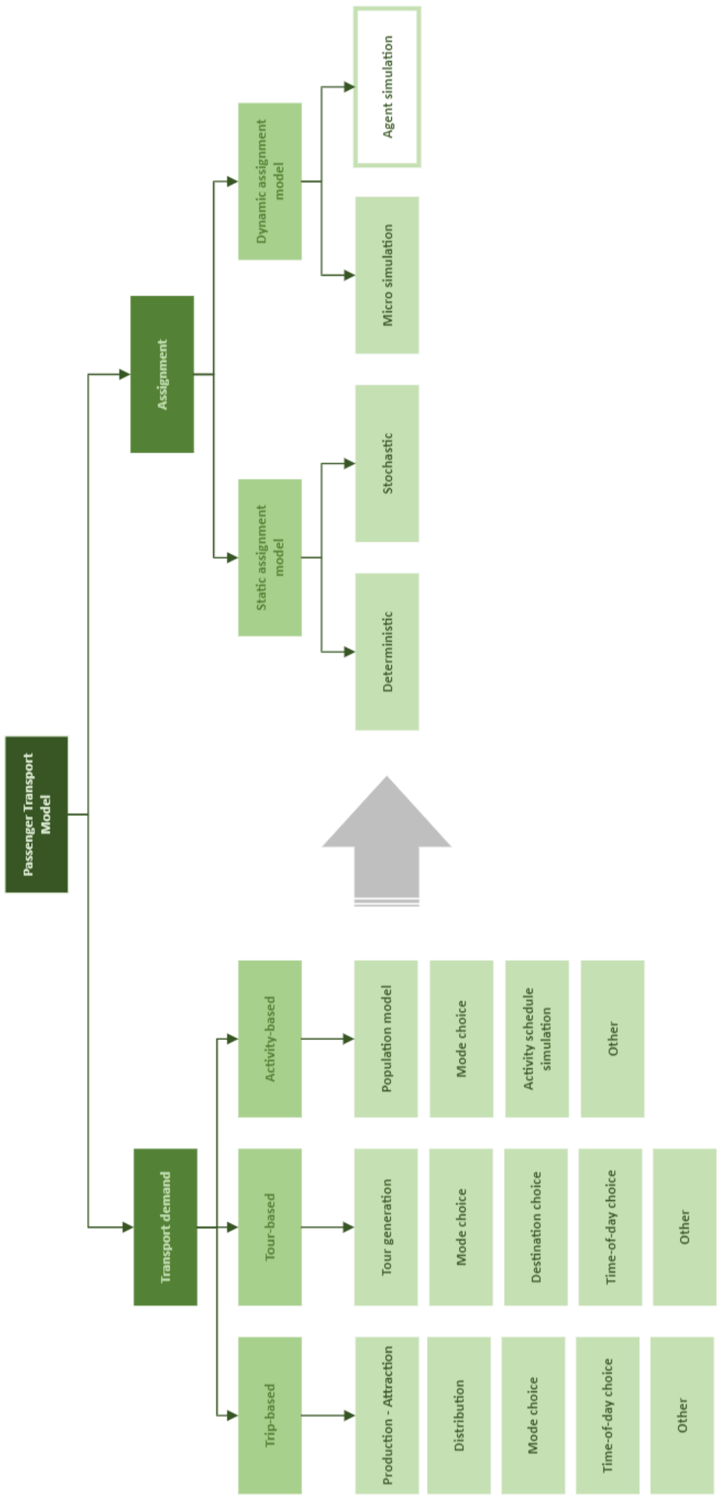
The transport demand model has broadly speaking three flavours:
- Trip based transport demand model,
- Tour based transport demand model,
- Activity based transport demand model.

The assignment model also has broadly speaking two flavours:
- Static assignment model,
- Dynamic assignment model.

This concept leads us to an overview as presented in Figure 2. As can be seen, the activity-based model is just one flavour of a transport demand model. The trip-based model and tour-based model are other types. Please note that the scheme provides a very general overview to show the place of an activity-based model in the bigger picture. The scheme is not intended to be complete.

[4] Some tend to call this a 'supply model' but these models are in most case based on some way of equilibrium calculations matching demand and supply. The output (loaded networks) reflects the transport demand, which implies that the output is also demand.

Figuur 2 General overview of a passenger transport model and its sub-models



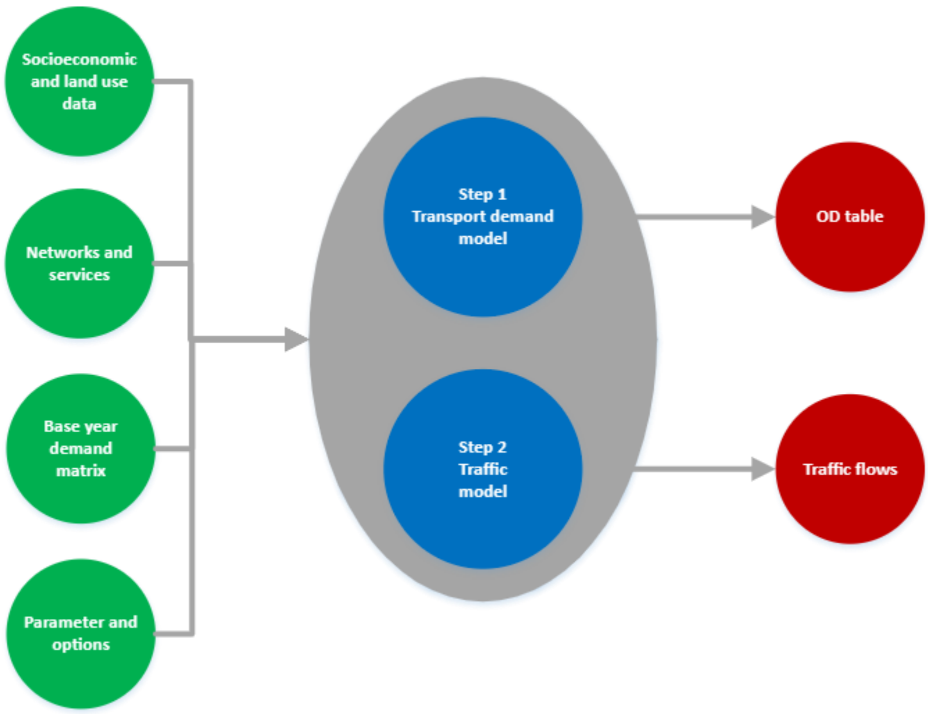
Source: Panteia

As can be seen, agent-based simulation is stored in a box under dynamic assignment model[5]. The reason for this will be explained later in this report (see 3.2.1). For the moment we leave it with the remark that based on the definition of an agent-based model, the conclusion is that according to the definition, these models do not (yet) exist, even though many experts use the term 'agent'.

2.3 What is input and output of a transport model?

The diagram below gives an overall impression of a transport model system in general. Some Dutch examples include models such as VMA (Model Municipality Amsterdam, VRU (Model Municipality Utrecht), Stravem (Model Province of Utrecht), BBMA (Model Province of Noord-Brabant), V-MRDH (Model Metropolitan Region The Hague-Rotterdam), VENOM (Model Vervoerregio Amsterdam), NRM (Dutch Regional Model), or LMS (Dutch National model), which fit into the model scheme.

Figuur 3 Model scheme



Source: Panteia

5 Some even see the combination of an activity-based transport demand model and a traffic assignment model as an agent-based model. For reasons explained later, we recommend not to call the entire model system 'agent-based'.

The *input* (usually) consists of a network, a base origin-destination table, socio-economic data, and parameters and options. There are other data, such as the number of parking spaces or the public transport services, but these can be captured under the heading 'network' to keep it simple. The parameters and options concern, on one hand, 'buttons' to adjust, for example, an index to represent the change in public transport fare or the share of e-bike use. On the other hand, they may concern model settings such as the number of iterations or the passenger car units.

The *dimensions* are not included in the diagram, but they do play an important role in the transport model system. Regarding the basic dimensions of a transport model we distinguish dimensions such as year, scenario, zone, purpose, mode, and time of day.

The *transport demand model* can be distinguished into trip-based, tour-based, and activity-based models. The Dutch models can be characterised as either trip-based (BBMA, VRU, V-MRDH) or tour-based (LMS, NRM, VENOM, VMA, Stravem). In terms of the classic 4-step model, the transport demand model broadly the first 3 steps (production-attraction, distribution, and mode choice). Although a tour-based or activity-based model use different sub-models, the essence of transport demand remains intact for these models as well. Whichever flavour we choose, the result is the volume (of persons, vehicles, etc) between an origin and destination, captured in an origin-destination table (OD-matrix).

To conclude, the *output* of the transport model system is (usually) an OD matrix (from the transport demand model) and a loaded network (from the traffic model). A variety of analyses are possible on these outputs. These depend on the policy question.

2.4 Applicability of a transport model

The use of the output is important for various users. The results often require further editing and processing. Here, too, policy questions play an important role. For example, the results can be used to answer different questions. The output can also serve as a source for further analysis. Think of a Social Cost-Benefit Analysis (SCBA), input for public transport studies, or environmental studies.

The use the output of the results varies. This can be done using separate modules that are used for post-processing the modelling results. This has the advantage that the model does not become too heavy by including different sub-models in one system.

The uses of the output are many and could include:

- Bottleneck analyses on the network
- Mobility analyses at origin-destination level
- In-depth analyses for Mobility-as-a-Service (MaaS)
- Input to other models at other geographical scales
- Social Cost-Benefit Analysis (SCBA)
- Environment and noise models
- Dynamic assignment models
- Network or data viewers

Depending on the questions, a transport model provides an answer directly or indirectly. Sometimes additional modules, software or procedures are needed to arrive at an answer.

3

3 Questions and answers

SIVMO has several questions on the activity-based models. Questions on definitions, methods, data, pros and cons, and applicability. These questions form the base of the report. This chapter provides answers to SIVMOs questions.

3.1 Questions

This section elaborates on the questions raised by SIVMO that need to be answered. Broadly speaking, these are questions about context, definitions, data, and pros and cons. Answering these topics is done in the next section.

3.1.1 Definitions of activity- and agent-based models

- What are the definitions of activity- and agent-based models?
- What is the difference between activity- and agent-based models.?
- Are there better terms activity- and agent-based models?
- Definitions for clear communication: Harmonisation of terminology for market and government.

3.1.2 Methodology

- Population: Size, study areas and synthesis versus simulation. What do you use it for?
- Stochasticity and noise: Meaning and implications within an activity-based or agent-based model. What do we mean by it? When does it occur?
- Area: To where does an AABM extend? Study area, area of influence, other?

3.1.3 Data needed for an activity- and agent-based model:

- Data for population modelling: base year, forecast years. What is needed?
- Data dimensions: Which ones are needed and to what level?
- Data access: Who does the data belong to, is it easy to access, do new sources need to be realised?
- Privacy and data ethics: Treatment of sensitive data and privacy regulations.
- Mapping activities: Necessary data for detailed modelling activities of a population.
- Uncertainties and data quality: Impact of uncertainties in data input and available data.
- Must-have versus nice-to-have data: Prioritisation of essential versus additional information.

3.1.4 Pros and cons and experiences with activity- and agent-based models

- Experiences of government and market parties: Experiences and challenges.
- Comparison modelling: activity-based model versus agent-based models versus discrete choice model and gravity model.

- Policy information and activity- and agent-based models: Possibilities and limitations of policy analysis compared to traditional models.
- Weighing advantages and disadvantages: Balancing the strength and complexity of activity- and agent-based models.
- When and how to apply activity- and agent-based models: Strategies for effective deployment of activity- and agent-based models.

3.1.5 Activity- and agent-based models in the Netherlands and abroad

- Inventory of activity- and agent-based models: Overview of existing practical applications.

3.2 Answers

3.2.1 Definitions of activity- and agent-based models

What are the definitions of activity- and agent-based models?
Activity-based models (AcBMs) are defined by their focus on the sequence of activities that individuals perform during the day, considering the context and interdependence of activities within households. These models derive transport demand from individuals' activities, reflecting a deeper understanding of travel behaviour due to lifestyle choices, social interactions, and economic constraints.

Agent-based models (AgBMs) share conceptual overlaps with AcBMs but extend the approach by simulating in a self-learning way the interactions between agents and the interactions between agents and their environment. This includes decision-making processes, adaptation to changing conditions and interactions between agents (without predetermined behaviour beforehand present), allowing complex systems and emergent behaviour to be investigated. To the (strictest) definition, agent-based models do not (yet) exist.

What is the difference between activity-based and agent-based models?
The main difference lies in their methodological focus. AcBMs focus on predicting activity patterns and transport demand based on detailed data on individual activity participation, timing, and location choices. AgBMs, on the other hand, emphasise the simulation of (self-learning) individual agents and their interactions within a system, capturing phenomena arising from the interactions of multiple agents, making them suitable for studying complex systems and emerging outcomes.

Are there better terms for activity- and agent-based models?
The discussions do not suggest other terms but emphasise the importance of terminological clarity. The distinction between "activity-based" and "agent-based" models is important for their application and understanding. While both models simulate individual behaviour within a transport system, "activity-based" specifically refers to models that focus on activity-based transport demand. The terms reflect the respective focus and capabilities of the models, indicating the need for precise language when discussing these modelling approaches. “Agent-based” is often used as an umbrella term. To avoid confusion, it would be better to describe what is meant by an “agent-based model”, as currently its meaning is versatile. Concerning the

abbreviations, if it concerns both activity- and agent-based models we propose to use 'AABM', if it concerns activity-based models we recommend the use of 'AcBM' and for agent-based models 'AgBM'.

Definitions for clear communication: Harmonisation of terminology.
For clear communication and to harmonise terminology between the market and government, it is suggested to be careful with terms and emphasise the underlying components such as population synthesis. It is recommended to avoid strict definitions but ensure clarity when specifying model components and requirements. As mentioned before, the term "agent-based" should not be used (at least in the Dutch realm), as the term is versatile. The advice is to describe the underlying models instead.

3.2.2 Methodology

Population modelling: Size, study areas and synthesis versus simulation.
The workshop and interviewees highlighted the importance of population delineation in AABMs, with an emphasis on creating a national synthetic population that any government agency can use. The main point lies in coordinating updates from different stakeholders with different timelines and software packages. The need for a detailed and customisable population synthesiser that can represent population diversity was highlighted. The modular development approach, which allows the addition of various population segments, was recognised as a methodological recommendation for the development of AcBMs.

Stochasticity and noise: Meaning and implications within an AABM.
Stochasticity in AABMs refers to the inherent variability in model simulation runs, which can lead to differences in outcomes even under the same conditions. Different strategies can deal with this variability, including using seeds for consistency and running multiple simulations to take averages. The use of 'seeds' is seen as a strategy or solution to assure reproducibility of results by the interviewees. The importance of transparency in communicating stochastic variability to stakeholders was highlighted, recognising that while accepting stochasticity is important for innovation in modelling, balancing innovation with stakeholder comfort is essential.

Geographical scope of an AABM: to where does it reach?[6]
Discussions on the geographical scope revealed a consensus that scope does not necessarily limit the applicability of AABMs. Flexibility in model design, sampling and the use of new technologies can help manage computational requirements. The potential of AABMs to generate activity for entire populations, regardless of geographical level, was highlighted, with a preference to start with a smaller, balancing geographical scope, computational efficiency and the depth of behavioural questions was acknowledged.

[6] The geographical scope is probably less of a problem in the Netherlands than in countries such as UK or Sweden with larger populations and/or land surfaces.

3.2.3 Data needed for an activity- and agent-based model

Data for population modelling: base year, forecast years. What is needed?
Demographic and behavioural data collected by means of surveys are considered important for population synthesis for both base year and forecast years. This includes socio-demographic data, travel or activity diaries and land use information. The results highlighted the need for detailed, up-to-date data to accurately reflect population and its dynamics over time.

Data types: Which ones are needed and at which level?
Essential data types are socio-demographic characteristics, activity patterns, travel behaviour and land use characteristics. The level of detail required depends on the purpose of the model, but in general, the more detailed the data, the more accurate the model. The importance of detailed activity and travel data was highlighted for capturing complex travel behaviour.

Data access: Who owns, is it easy to access, do new sources need to be tapped?
Data access can be an issue and often requires negotiations with multiple stakeholders, including government agencies, consultants, and data providers. The interviews and the workshop highlighted the importance of establishing clear data sharing agreements and exploring big data sources to improve the accuracy and relevance of models.

Privacy and data ethics: Handling sensitive data and privacy regulations.
Ensuring privacy and complying with data ethics are of utmost importance. Models should use anonymised data and comply with (EU) privacy regulations. Some interviewees highlighted the need for privacy-protecting techniques in data collection and model development.

Activity mapping: Necessary data for detailed modelling of activities of a population.
Detailed activity data, including the type, timing, and location of activities, are needed to map the daily routines of the population. This requires extensive travel or activity diaries and land use data to accurately model activity patterns and their impact on travel demand. This also includes activities at home to address 'electronic travel' instead of 'physical travel'.

Uncertainties and data quality: Impact of uncertainties in data.
Uncertainties and data quality can affect model outcomes. There are different strategies to address uncertainties, including sensitivity analysis and data validation techniques. Ensuring high data quality through rigorous data collection and pre-processing is essential for reliable model predictions.

Must-Have Versus Nice-to-Have Data: Prioritisation of information.
Essential data for AcBMs include detailed demographic profiles, activity and travel diaries and network data. Nice-to-have data include real-time mobility data, social network information and environmental data, which can add depth to the model but are not essential to the basic functionality of the model. The interviewees and workshop participants emphasised the importance of prioritising data acquisition based on model objectives and resource availability.

3.2.4 Pros and cons and experiences with activity- and agent-based models

Experiences of governments and market players
Different governments and market players have recognised the potential of AABMs for detailed analysis of individual and group behaviour in transport systems. However, the complexity and computational requirements of these models are an issue for widespread application. Experience shows that there is a need to balance model detail with practical applicability.

Modelling comparison: AABM vs discrete choice and gravity models
AABMs offer a more nuanced understanding of individual behaviour and interactions within a system, in contrast to the traditional transport models. The main advantage lies in their ability to simulate specific scenarios and policies at a granular level, although at the cost of higher complexity and computational requirements.

Policy information and AABMs
AABMs are promising in providing detailed insights for policy analysis, especially in scenarios where individual behaviour and interactions significantly affect system dynamics. They make it possible to examine complex policy that are not easily captured by traditional models. However, their effectiveness depends on the availability of detailed and accurate data.

Balancing advantages and disadvantages
The advantages of AABMs include detailed behavioural modelling, flexibility in scenario analysis and the potential for nuanced policy evaluation. The disadvantages mainly relate to the high data requirements, computational intensity, and steep learning curve for implementers.

When and how to apply AABMs
The decision to apply AABMs should be guided by the specific needs of the study, the availability of detailed data and the capacity to manage complex models. They are particularly useful when detailed behavioural insights are needed to inform policymakers or when traditional models cannot capture the complexity of transport systems. However, the timing for adopting AABMs depends on an organisation's readiness to deal with their complexity and data requirements.

3.2.5 Activity- and agent-based models in the Netherlands and abroad

Inventory of activity- and agent-based models: Overview of practical applications.
The application of AABMs to policy issues worldwide, shows a growing recognition of their potential in addressing transport and spatial planning issues. These models provide detailed simulations of individual and household behaviour, enabling a deeper understanding of travel demand and the impact of policy interventions.

AABMs have been applied in different geographical contexts, with certain models being more suitable for local issues, such as cycling, while other are more applicable at a regional level, such as regional public transport. Activity-based models, for example, are highlighted for their effectiveness in settings, where understanding of local behaviour is important. Conversely, at the national level, other models, such as tour-based models, may be preferred, as seen in Sweden’s efforts to develop a national model. This distinction highlights the flexibility of the models and their tailor-made application based on the specific needs of the studied region.

It is believed that AABMs lead to better underpinned policy decisions by providing a deeper understanding of human behaviour. This is particularly important for policies that require detailed analysis of behavioural responses, such as policies related to social equity, spatial densification, demographic shifts, and emerging technologies such as autonomous vehicles and e-commute. However, the complexity of these models has its problems, especially in terms of understandability and accessibility for policymakers. Efforts to make these models more understandable without simplifying reality are important for their effective use in policymaking.

The development and application of AABMs require detailed data of individuals and households, highlighting the need for synthesis methods to generate comprehensive datasets where direct data collection is not feasible. The integration of big data sources, such as mobile and Floating Car Data, have been explored to further enrich these models. However, issues remain in terms of data privacy, ethics, and reliability of these new data sources. The effectiveness of AABMs in policy contexts is dependent on the quality and depth of the underlying data, requiring continuous efforts to improve data collection and synthesis methods.

Practical applications of AcBMs reveal their potential and their issues. In Copenhagen, for example, an AcBM has already become a reality, representing a shift towards more detailed and dynamic transport planning tools. However, the time and financial investments required to develop and maintain these models comprise obstacles, especially when transitioning from traditional models. It is expensive to develop and maintain two models at the same time (one phasing out, while the other is starting up). Experts suggests a cautious approach, balancing the desire for advanced modelling capabilities with the practicalities of model development, maintenance, and stakeholder engagement.

The global status of AcBMs in addressing policy questions reflects a mature field with significant potential to transform our understanding and management of transport systems. While challenges remain, particularly in terms of model complexity, data requirements and stakeholder engagement, the benefits of more accurate, behaviourally rich models in informing policy and planning decisions are clear. As the field evolves, continued innovation in modelling practices, data integration and stakeholder communication will be key to unlocking the full potential of AcBMs in shaping sustainable and efficient transport policies worldwide.


IF YOU
CHANGE
NOTHING
NOTHING
WILL
CHANGE

4 Recommendations and advice

SIVMO prepares a transition towards AABMs. What can be recommended concerning data, methods, and software? What can be recommended concerning the transition, process and collaboration with stakeholders, consultants, governmental bodies, and academics? This chapter provides an outlook.

4.1 Technical steps for model transition

The transition towards activity-based models is recommended to enhance travel behaviour insights and support transport policy and infrastructure planning. The transition involves several key steps:

- *Immediate action*. The transition to activity-based models (AcBMs) is necessary for improving the detail and accuracy of travel behaviour analyses in the Netherlands. These models outperform traditional approaches by providing deeper insights into travel behaviour and the impact of transport policies and infrastructure developments. Despite initial explorations in the late 1990s that positioned the Netherlands as a pioneer in this field, the actual deployment of a functioning activity model has stagnated. Given the advances in methodology and data, alongside the global momentum towards activity-based modelling, there is no justification for further delay. The knowledge on methodologies, data, and best practices available internationally underlines to proceed without hesitation.
- *Population synthesis*. Creating a country-wide population synthesis is an important, no-regret first step. This task, ideally undertaken by SIVMO, will benefit all government agencies by being a versatile enough model to accommodate different transport models. It is important to implement a protocol for annual updates of the model's output so that regions can independently move forward with their own transport model. The choice of methodology - the accessible Iterative Proportional Fitting (IPF) or the machine learning approach - should be determined for the intended future direction of the model. Although machine learning has the potential to efficiently process complex, multidimensional data, it may be more advantageous to start with IPF for those new to the concept of population synthesis because IPF is easier to understand for transport modellers (the often-used Furness or Fratar techniques are simple IPF methods). However, one needs to understand that IPF is limited in getting a rich and heterogenous synthetic population. An option is to walk a parallel path and start using machine-learning to also learn this to use and apply this technique.
- *Pilot model*. It is recommended to select at least one pilot model of one of the SIVMO partners to demonstrate the integration of population synthesis. This model should exist in both traditional and revised forms to allow comparative analyses and to promote a better understanding of the synthesis process within transport modelling. This two-version approach will facilitate the transition to more advanced modelling techniques.

- *Improve household travel survey (ODiN)*. Improving data from household surveys is important for refining activity-based models. Traditional surveys have laid a solid foundation but lack details on activities at home and interaction with other household members, which are becoming increasingly relevant with the rise of remote work and digital engagement. Supplementing surveys to capture these aspects will improve the model's ability to accurately plan activities, an essential component of activity-based modelling. Given the time needed to implement these questions, it is advised to start adapting the surveys as soon as possible.
- *Stepwise development*. Developing an AcBM is preferably be done incrementally rather than all at once. Familiarisation with new modelling functions such as population synthesisers should precede the integration of more complex elements such as activity planners. This incremental approach can be fruitful, for the reason of consistency with the current models and to keep a not to steep learning curve.
- *Handling stochasticity*. The stochastic nature of an AcBM results needs to be addressed. Variability in simulation results, even with identical inputs, requires careful consideration. Options include accepting this variability as a reflection of reality, using 'seeds' for reproducibility, or using semi-Monte Carlo techniques. Given the importance of reproducibility in the Netherlands, it is advisable to further explore the use of 'seeds' or semi-Monte Carlo methods.
- *Software development*. In the area of software development, SIVMO's preference to avoid a vendor lock-in by advocating open-source software is commendable. The development and deployment of activity-based modelling software should embrace an open-source philosophy, ensuring accessibility to all Dutch developers and users. This could mean starting or joining open-source communities or initiating new software projects, fostering a collaborative environment that accelerates innovation and knowledge sharing.
- *Software platforms*. The trade-off between software platforms for activity-based modelling presents a problem, given the wide variety of options available, each with its own advantages and limitations. Platforms such as Omnitrans, Vision (Visum, Vissim, etc), Cube Voyager, EMME, TransCad and Aimsun offer varied capabilities but also come with significant costs, especially when weighed against their use. To circumvent the financial burden and avoid the risk of vendor lock-in, it is recommended to pursue the development of an activity-based model (AcBM) as an open-source programme or module. This strategic approach not only promotes cost efficiency, but also ensures compatibility and flexibility between different platforms. Most existing platforms are designed to support tailor-made software integration, which significantly increases the scope for innovation and adaptability. Opting for open-source development allows government agencies and market players to use their preferred platforms while accessing and contributing to a common pool of resources and tools. This collaborative model approach facilitates the sharing of advances and best practices, improving the overall efficiency and sustainability of transport modelling efforts.
- *Explore hardware*. Investigate advanced hardware solutions to address the computational demands of developing and running AcBMs. Consider using technologies like cloud computing and parallel processing as effective strategies for managing the computational demands. This way it will be feasible to keep the computing time not too high.
- *Necessity of an AcBM*. Evaluating the need for AcBM within a specific context requires careful consideration of policy and planning objectives. It is necessary to consider whether the complexity of an AcBM is justified for the questions at hand.

In many smaller municipalities, the utility of transport models is not as great as the dynamics captured by AcBMs, suggesting that a simpler model could suffice for their needs. This assessment should precede any investment of resources or development initiatives to focus efforts on models that offer benefits in addressing targeted policy questions. This strategy ensures that resources are used efficiently, prioritising projects with the greatest potential impact on planning and policy formulation. Aligning technological advances in modelling with the needs and priorities of municipalities and government agencies promotes a more focused and effective approach to transport modelling and infrastructure development.

4.2 Organisational steps for model transition

Organisational steps for the transition to activity models in the Netherlands require a multifaceted approach. These include:

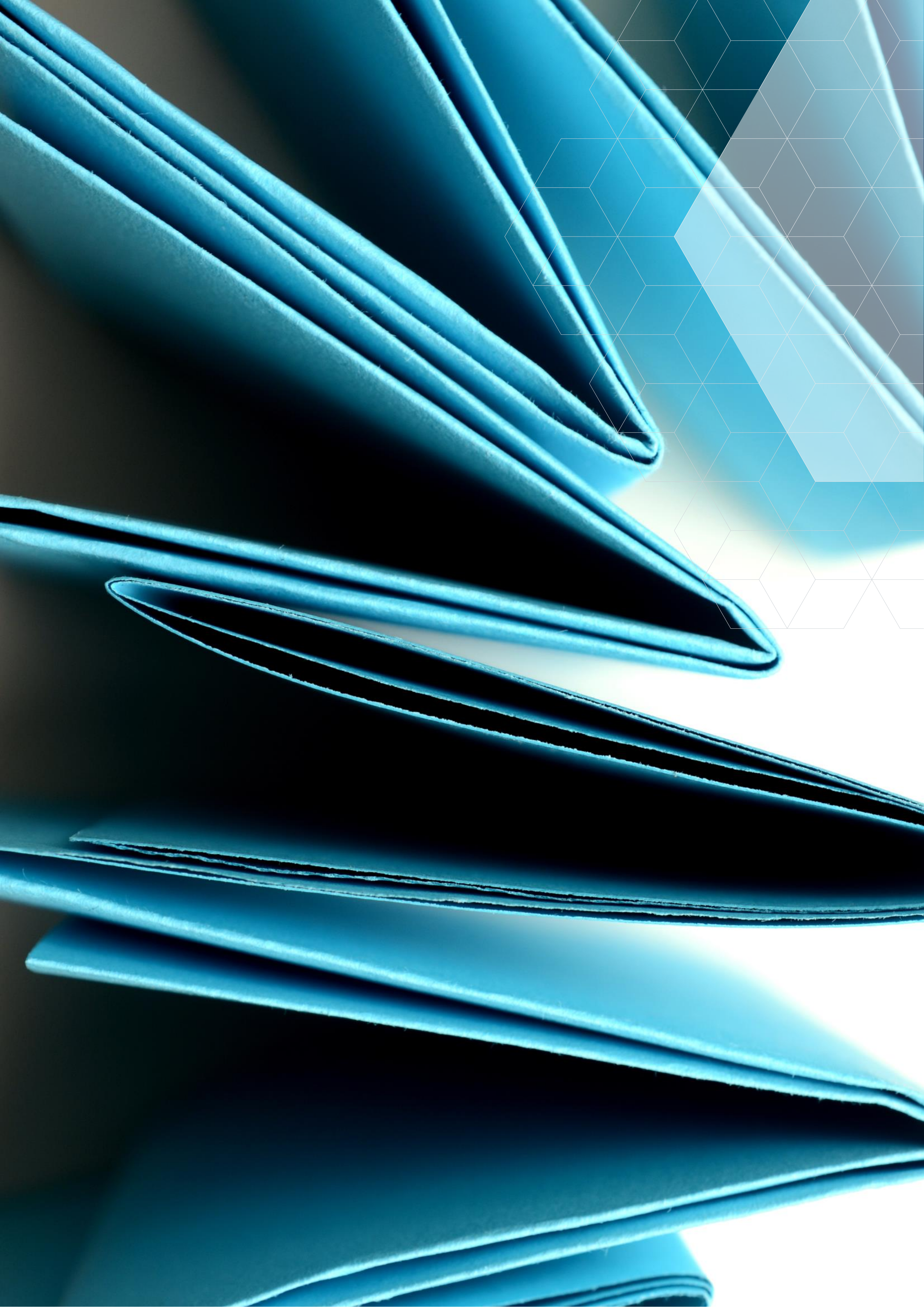
- *Training and knowledge building*. There is a need for training programmes to strengthen the understanding and application of activity-based models. Given the limited knowledge base in the Netherlands, customised training for various stakeholders - students (as future workforce), government agencies (both current and future customers and users), market players (potential developers and users) and academics (key to future AABM developments) - is needed. Collaboration, especially between governments, market players and universities, is recommended to effectively design and implement these programmes.
- *Forming an AABM alliance*. Strengthening cooperation between academics, market players and government agencies is essential because of the narrow range of AABM (AcBM and AgBM) knowledge in the Netherlands. Starting an Alliance for the Development and Application of AABMs, like Rijkswaterstaat's successful Freight Transport Model Alliance, is recommended. This alliance would facilitate a cooperative environment for developing and applying AABMs, encouraging knowledge sharing and collective progress rather than competition.
- *Model and software development*. Developing an activity-based model (AcBM) requires in-depth knowledge of both the underlying methodologies and software engineering aspects. It is recommended to include not only market players with expertise in methodologies but also software developers in the alliance to ensure that the software meets high development standards. The inclusion of academic institutions and universities ensures that the latest research findings are quickly and efficiently integrated into the models.
- *Collaboration with other stakeholders*. Establishing partnerships with other stakeholders such as public transport operators like NS as well as international entities is important. These partnerships facilitate the exchange of data, model insights and best practices. Collaborating with a national and international network enriches the knowledge base and introduces global best practices into the local context. The EABMA (European ABM Association, currently in formation) is a good opportunity to connect with partners Europe wide.
- *Preparing policymakers and decision-makers*. Prior to the development and implementation of an AcBM, it is essential to prepare policymakers and decision-makers, who are often behind these initiatives. They should be informed about the rationale, methodology and expected outcomes of an AcBM. Anticipating possible differences in results compared to traditional models is also vital to prepare them for the transition to this new modelling technique.

Glossary

Terminology	Description
Activity scheduler	An activity scheduler is a component within an activity-based model that determines the timing, sequence, and duration of daily activities for individuals, considering the spatial and temporal constraints. It simulates how individuals allocate their time among various activities, such as work, leisure, and travel, thereby influencing their travel decisions and patterns within the transportation network.
Activity-based model (AcBM)	Activity-based models focus on understanding travel demand stemming from individuals' daily activities, considering the location, duration, and purpose of these activities. They provide a detailed simulation of travel patterns by modelling how these activities influence travel decisions and behaviour.
Advanced analytics	Advanced analytics comprises a set of analytical techniques and technologies applied to (transportation) data to uncover insights, predict future trends, and make informed decisions. These techniques, including machine learning, data mining, and predictive modelling, enable the extraction of valuable information from complex datasets, supporting the optimization of transportation systems, enhancement of mobility services, and improvement of infrastructure planning.
Agent-based model (AgBM)	Agent-based models simulate the interactions of autonomous agents (such as individuals or vehicles) with each other and their environment, incorporating the capacity for agents to learn and adapt based on their experiences.
Big data	Big data refers to the vast and complex datasets generated from a multitude of sources, including GPS devices, sensors, social media, and transaction systems, which are characterized by their volume, velocity, and variety. This data enables the detailed analysis of travel patterns, infrastructure or public transport usage, and user preferences, facilitating the development of more responsive and efficient transportation systems through advanced analytics and modelling techniques.
Iterative proporional fitting (IPF)	Iterative Proportional Fitting (IPF) is a statistical technique used to adjust and refine the distribution of a dataset to match known marginal totals (for example

	rows and columns), without altering the dataset's original structure. This method is particularly utilised in population synthesis and trip distribution models to ensure that simulated data aligns with actual demographic and travel patterns, thus enhancing the accuracy and reliability of transport demand models.
Machine learning	Machine learning refers to the development of algorithms capable of learning from and making predictions or decisions based on data, without being explicitly programmed for specific tasks. This approach enables the analysis and interpretation of large datasets, improving topics such as traffic management, demand forecasting, and the personalization of travel services through adaptive and predictive models.
Microdata	Microdata refers to detailed, individual-level data that captures the characteristics and behaviours persons or households. These detailed data, which can include information on travel choices, routes, modes of transportation, and socio-demographic attributes such as age or occupation, is essential for analysing travel behaviour and calibrating models.
Microsimulation	Microsimulation comprises a methodology that simulates the movement and interaction of individual entities, such as vehicles or pedestrians, on a transport network, to analyse specific behaviours and outcomes at a detailed level. This technique facilitates the examination traffic flow or congestion patterns and provides insights into the effects of various policies or infrastructure changes.
Model calibration	Model calibration involves the adjustment of parameters within a transport model to ensure that the model's outputs, such as traffic flows, travel times, and mode choice distributions, closely align with observed data from the real world. This process enhances the model's accuracy and reliability, to allow good predictions of the impacts of policies, infrastructure changes, or spatial planning.
Model validation	Model validation is a procedure of comparing a model's outputs with independent sets of observed data, not utilized during the calibration phase, to assess the model's accuracy, plausibility, and its ability to generalize to conditions beyond those it was specifically calibrated for. This step ensures the model's reliability and credibility in forecasting transport demand and network performance under varied scenarios and policy interventions.
Population synthesis	Population synthesis is a statistical technique used to generate a representative population of individuals or

	households based on aggregated socio-economic data and survey samples, mirroring the demographic and socio-economic characteristics of a real-world population. This synthesized population serves as the foundation activity-based models, enabling the analysis of travel behaviour and policy impacts at the individual and household levels within a transport system, in a GDPR (General data protection regulation) friendly manner.
Seeds	Seeds refer to initial values used to set up the random number generators that are used in the stochastic components of simulation models. Seeds ensure the reproducibility of simulations, allowing modellers to generate and reproduce consistent results and to analyse the variability in outcomes due to changes in model inputs or assumptions, rather than variations in random number sequences.
SIVMO	SIVMO stands for '**S**amenwerkingsverband en **I**nnovatie **V**erkeers**m**odellen door **O**verheden' (Collaboration and Innovation of Traffic Models by Governments). SIVMO comprises of Rijkswaterstaat, ProRail, Province of Noord-Brabant, Province of Utrecht, Vervoerregio Amsterdam, Metropolitan Region of Rotterdam and The Hague, and the municipalities of Amsterdam, Rotterdam, The Hague, and Utrecht. The aim is to collaborate on the development an application of advanced transport models.
Social equity	Social equity refers to the fair and just distribution of transport resources, services, and opportunities across all societal segments, ensuring that accessibility and mobility benefits are equitably shared. It emphasises the removal of barriers and the inclusion of marginalised communities in transport planning and policymaking, aiming to achieve a more inclusive and equitable transport system that addresses the needs of all users, regardless of their socio-economic status, age, or ability.
Stochasticity	Stochasticity refers to the randomness and variability in models and simulations to reflect the unpredictable nature of travel behaviour. This approach acknowledges the inherent uncertainty, allowing for more realistic and robust predictions of travel patterns and network performance.



Annexes

Annex 1 References

1.1 Introduction

To answer part of the questions, we carried out a desk-research. This mainly involves literature searches. We collected books, book chapters, articles, presentations, and columns from the following sources:

- Google Scholar, Elicit.org, ResearchGate.net.
- Recent papers presented at ETC and CVS in the last three years.
- Other literature available from Panteia, SIVMO, governments, market players and knowledge institutions.

We collected publicly available information, that is articles, papers, and reports in PDF format. This led to a total of around 300 sources. The complete list is given in this annex. This list is made accessible for SIVMO.

We acknowledge the fact that there is more literature than we have considered here. Paid literature for example, has been only considered partially. This may have left us with some unexplored sources. But within the framework of this project, we feel that the available sources gave us sufficient insights to provide a first base to answer the questions at stake and to carry out the interviews and workshop.

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1.3 Links

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Travel Forecasting Resource:
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Annex 2 Selection of references

2.1 Introduction

From the long list of references, a selection of references was made that potentially could answer the different questions concerning the inventory of activity-based and agent-based models.

2.2 Selected references

Reference	Summary
Adenaw, L. Bachmeier, Q. (2022). "**Generating activity-based mobility plans from trip-based models and mobility surveys**". Applied Sciences, 12, 8456.	The article discusses the development of a method to create realistic activity-based mobility plans using existing trip-based models and mobility surveys. This approach aims to bridge the gap between macroscopic trip-based models, which are prevalent but lack individual-level detail, and complex activity-based models that provide microscopic simulation but are seldom available due to their complexity. The method presented effectively combines the broad characteristics from general mobility surveys with the specific traits from trip-based models to generate mobility plans that are accurate both on a microscopic (individual) and macroscopic (broad pattern) level. This hybrid model is positioned between trip-based and activity-based approaches, offering a practical alternative when a full-scale activity-based model is unfeasible. The research focuses on car mobility in Munich, demonstrating that the model successfully replicates real-world mobility demands. It provides a scalable solution applicable in various settings where comprehensive, detailed mobility data is required but the development of complex models is not practical. The paper contributes to the field by addressing a research gap and offering an efficient method to generate detailed mobility plans, applicable primarily in urban settings like Munich and on weekdays.
Algers, S. Eliasson, J. Mattsson, L.-G. (2001). "**Activity-based model development to support transport planning in the Stockholm region**." 41st Congress of the European Regional Science Association, Zagreb, Croatia, August 29 - September 1.	This conference paper examines the shift in focus from traditional infrastructure investment to sustainable transport systems, influenced by the rapid penetration of information technology in all societal sectors. The paper highlights how these changes affect transport system usage, prompting a reconsideration of the suitability of existing transport modelling tools for future urban and regional planning challenges. A literature survey on activity-based models is conducted,

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	particularly focusing on their applicability to medium-sized cities like Stockholm. The paper discusses the development of these models, considering their theoretical appeal, empirical validity, usefulness in planning, data requirements, and implementation issues. This inquiry is set against the backdrop of anticipated planning issues over the next decade, emphasising the need for models that can adapt to and effectively inform the evolving demands of sustainable transport planning.
Allen Jr. W.G. Contiero, F. (2018). "**Simplified tour-based model**". Paper presented at ETC 2018 Dublin.	The Simplified Tour-based Model (STM) offers a more streamlined alternative to the complex activity-based model for travel demand. STM retains the individual round-trip tour structure while being better suited for many urban areas, providing a more efficient improvement over the traditional four-step approach in travel modelling.
Anggraini, R. (2009). "**Household Activity-Travel Behavior: Implementation of Within-Household Interactions**". Eindhoven University of Technology.	This thesis explores the evolution of travel demand modelling in transportation research, from traditional four-step models to the more comprehensive activity-based approach. It specifically focuses on household decision making, resource allocation, joint activity participation, and car allocation within the ALBATROSS model framework. The study aims to enhance the representation of interdependencies in travel behaviour, offering insights into more realistic and nuanced urban travel demand predictions.
Aspital, D. Chittock, L. Oliver, M. Gordon, A. (2020). "**Activity chain demand modelling for electric vehicles**". Paper presented at ETC 2020 in Milan.	The UK's Transport Analysis Guidance (TAG) prefers tour-based modelling, commonly represented as production-attraction (PA) pairs. However, this approach has limitations in capturing complex travel behaviours. The paper discusses the transition to more nuanced activity-chain demand modelling, distinguishing between aggregate and microscopic methods, and addressing the terminological ambiguities in the field.
Axhausen, K.W. (2006). "**Definition of movement and activity for transport modelling**". In: Handbooks in Transport 1: Transport Modelling.	The chapter aims to establish a coherent set of definitions for movement and activity in the context of transport modelling. It discusses the complexities in capturing this information through surveys, focusing on the stage, activity, and reference location. The objective is to refine data collection for more accurate transport models.
Baqueri, S.F.A. Adnan, M. Kochan, B. Bellemans, T. (2019). "**Activity-based model for medium-sized cities considering external activity-travel: Enhancing FEATHERS**	The article addresses the evolution of travel demand modelling from traditional four-step models to advanced Activity-Based Models (AcBM). AcBMs are noted for their ability to test various policy scenarios by considering complete activity-travel patterns of individuals. However, most AcBMs restrict activities to

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framework". Future Generation Computer Systems.	within the study area, leading to distorted travel patterns. To address this, the study introduces a framework within the FEATHERS AcBM operational for Flanders, Belgium, which incorporates residents' travel and activities outside the study area. This inclusion of the Catchment Area (CA) in destination choice models allows for more accurate representation of travel patterns. The methodology involves using detailed land use information within the study area and open-source land use data for the CA, reducing data collection efforts. The approach was tested in three medium-sized regions within Flanders, demonstrating improvements in model outputs compared to larger study areas. A comprehensive validation framework compared the AcBM for medium-sized regions against the AcBM for Flanders, confirming the methodology's validity. This study suggests that including external activity-travel in AcBMs can lead to more accurate and efficient models for medium-sized regions.
Bastarianto F.F. Hancock, T.O. Choudhury, C.F. Manley, E. (2023). "**Agent-based models in urban transportation: review, challenges, and opportunities**". European Transport Research Review (2023) 15:19.	This paper reviews the application of agent-based models in urban transportation research. Through a literature analysis of 309 documents from the Scopus database and content analysis, it identifies research gaps, challenges, and potential directions for future research. The study reveals nine distinct clusters of research methods and highlights issues like computing efficiency, model calibration, and replicating complex transportation systems. The aim is to guide researchers in understanding and enhancing agent-based models in urban transportation contexts.
Bazzan, A.L.C. Klügl, F. (2013). "**A review on agent-based technology for traffic and transportation**". The Knowledge Engineering Review, p.1-29. Cambridge University Press.	This document is an article focusing on the application of agent-based technologies in traffic and transportation engineering. Over recent years, the intersection of traffic transportation and artificial intelligence, particularly agent and multiagent systems, has seen significant advancements. These technologies have been instrumental in addressing various complexities in traffic and transportation systems, which have evolved due to changes in lifestyle and transportation modalities. The article reviews the literature on agent-based traffic modelling and simulation, as well as traffic control and management. It discusses the progress made in these areas, including the successful reproduction of human behaviour in traffic scenarios, simulation of pedestrian and vehicular flow, distributed optimization, and control management across various systems like public transportation and air traffic.

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	The article also explores the challenges and future research opportunities in this field, emphasizing the role of agent-based approaches in efficiently managing traffic and transportation systems, both at the individual and societal levels. Agent-based methods are particularly suited due to their ability to handle the geographical, functional, and temporal distribution of data and control, and the dynamic interaction among system participants and their environments. The article contributes to the ongoing debate about modelling and improving traffic and transportation systems, highlighting the potential of these technologies in designing and controlling intelligent transportation systems (ITS).
Bekhor, S. (2014). "**Stability analysis of activity-based models: case study of the Tel Aviv transportation model**". EJTIR Issue 14(4).	The document focuses on the Tel Aviv activity-based model and its structural similarities with other activity-based models. It explores the challenges of achieving model convergence due to the random nature of individual tour generation and the limitations of static traffic assignments. The paper presents an analysis of uncertainty sources in the AcBM, including simulation errors and population sampling. It investigates three different averaging procedures to achieve stable model results, highlighting the need for practical considerations in setting up these procedures. AcBMs simulate the decision processes of individuals based on randomly generated synthetic populations, making the outcome inherently random. Mitigating these random effects and ensuring the reproducibility of model results is critical. The findings also reveal that using population sampling doesn't significantly reduce the number of iterations needed for achieving accurateAcBM results. The study concludes that the variability in model results is proportional to the inverse of the square root of the population sample size. It suggests that future research should focus on more robust averaging procedures and the foundational aspects of population synthesizing, as these factors significantly influence the variability and accuracy ofAcBM results.
Brederode, L. (2023). "**Vervoersvraag-modellering: Transitie van Macro- naar Microscopisch**". Deventer: DAT.mobility.	This document is a presentation by Luuk Brederode, focusing on the transition from macroscopic trip-based to microscopic tour-based models in transportation modelling. The presentation explores the relationship between macro/micro and activity- and agent-based

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	models, highlighting the issues posed by statistical noise in micro-models. It differentiates between operational micro-models, used for describing current situations, and strategic micro-models, which are more complex and are used for predicting future effects. The latter face issues with statistical noise affecting the comparability of model outcomes. Brederode also notes the ongoing trend in mobility from ownership to usage (shared mobility), which necessitates a shift to micro-models, including 'regular' microscopic models, activity-based models (adding time/space consistency), and agent-based models (incorporating self-learning parameters). The presentation underscores the significance of these trends in the Netherlands and the emerging applications of micro-models in strategic transportation planning.
Canella, O. Engelson, L. Berglund, S. (2023). "**Microsimulation variability in a fully disaggregated agent-based transport model for Sweden**". Paper presented at ETC 2023 in Milan.	The study describes the impact of random seeds on the appraisal of infrastructure projects using a fully disaggregated agent-based transport model in Sweden. It focuses on how sensitive project assessments are to stochastic elements in microsimulation. The authors conclude that while the effect of random seeds is minimal for large projects, it could be significant for smaller projects. Overall, other uncertainties like input and model specification seem to have a greater influence on project appraisal.
Castiglione, J. Bradley, M. Gliebe, J. (2015). "**Activity-Based Travel Demand Models A Primer**". Transportation Research Board of the National Academies.	This report discusses the development and application of activity-based travel demand models to support informed decision-making in transportation agencies. It highlights the advantages of activity-based models in replicating actual traveller decisions and improving travel pattern forecasts. The guide is divided into two parts, offering insights for managers, planners, and modelers, as well as discussing the integration of activity-based models with dynamic network assignment models.
Chu, Z. Cheng, L. Chen, H. (2012). "**A review of activity-based travel demand modeling**". CICTP 2012. ASCE 2012.	The paper provides an extensive overview of the developments in activity-based travel demand modelling, a field that has garnered significant interest over the last three decades. These models, which represent the third generation of travel demand models, conceptualize travel as a derivative of the demand for participation in various activities. The paper initially outlines the history of travel demand approaches before delving into four distinct methods used in activity travel analysis. It also explores the practical applications of these methods in addressing

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	current policy and planning issues. The article aims to identify and articulate recent advancements in the field, focusing on the nature and scope of these developments and their implications for forecasting travel behaviour and usage under varying socio-economic scenarios and land-use configurations. These advancements mark a shift from traditional statistic-oriented trip-based models to more behaviour-focused activity-based models in transportation planning.
Clarke, P. Davidson, P. Thomas, A. (2008). "**Migrating Four-Step Models to an activity-based Modelling Framework in Practice**". Paper presented at ETC 2008 in Leiden.	The paper discusses the transition from traditional Four-Step Models to activity-based Models in transportation planning, emphasizing the latter's policy responsiveness. Despite the challenges and resource intensiveness of conversion, activity-based Models offer improved forecasting for policymakers. The paper draws on the authors' experiences in migrating models using existing data sources.
Clerx, W. (2022). "**Strategische verkeersmodellen en de mobiliteitstransitie**". In: NM magazine 17e jaargang, nr. 2, 2022, pp 11-13.	Strategic traffic models have long been a vital tool for understanding and predicting both current and future usage of transportation networks. However, as mobility undergoes significant transformation due to factors such as technological advancements and changing societal attitudes, these models need to evolve. The core issue is one of 'differentiation'—these models must adapt to capture increasingly complex variables, from differing urban densities to attitudes towards health and climate. Enhanced data management and multi-stakeholder collaboration are also underscored as important elements in the refinement and implementation of these adaptive, more detailed models.
Davidson, B. Vovsha, P. Freedman, J. (2011). "**New Advancements in Activity-Based Models**". Australasian Transport Research Forum 2011 Proceedings, 28 - 30 September, Adelaide, Australia.	This paper discusses significant recent developments in Activity-Based Models in the United States, particularly in their application for extensive regional travel models by Metropolitan Planning Organisations (MPOs). It highlights progress in AcBMs in regions like San Diego and Phoenix. San Diego's AcBMs now feature a finer spatial resolution for location choices, improving comprehension of public transport access and non-motorised travel, and including variables attuned to transit-oriented development strategies. In Phoenix, AcBMs explicitly model seasonal variations in travel demand and have introduced submodels for specific segments, such as university-related travel and households owned by seasonal residents. Furthermore, the paper elaborates on modelling travel time reliability based on perceived highway time and congestion levels, and the inclusion of parking choice models in congested Central Business Districts. It also describes

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	the evolution of seven regional AcBMs under the Coordinated Travel - Regional Activity Modelling Platform (CT-RAMP), underscoring the aim to augment behavioural realism in these models and their application to specific projects and policies for various MPOs.
Davidson, W, Donnelly, R. Vovsha, P. Freedman, J. Ruegg, S. Hicks, J. Castiglione, J. Picado, R. (2007). "**Synthesis of first practices and operational research approaches in activity-based travel demand modeling**". Transportation Research Part A: Policy and Practice, 41(5), 464-488.	This paper discusses the evolution of regional travel models in the United States from conventional to behaviourally realistic activity-based models. These models focus on daily activities, employ a tour-based structure for modelling travel, and use micro-simulation techniques at the individual level. While these models offer conceptual advantages, practical issues and debates persist. Successful implementations demonstrate their viability, but widespread acceptance hinges on demonstrating their practicality and forecasting accuracy.
Drchal, J. Certický, M. Jakob, M. (2015). "**Data driven validation framework for multi-agent activity-based models**". arXiv:1502.07601v2 [cs.MA], 3 Mar 2015.	This document introduces a novel six-step Validation Framework for Activity-based Models (VALFRAM) that leverages historical real-world data for assessing the validity of activity-based models in transport and mobility. Activity-based models, a subset of agent-based models, are essential for structuring daily activities and travel behaviours of agents. Despite their growing importance, there has been a lack of focused work on their statistical validation. VALFRAM addresses this gap by providing a comprehensive framework to compare the temporal and spatial properties, as well as the structure of activity schedules, with real-world travel diaries and origin-destination matrices. The framework's effectiveness is demonstrated through its application to three different real-world activity-based transport models, confirming its utility in the field.
Ferdous, N. Vana, L. Bowman, J.L. Pendyala, R.M. Giaimo, G. Bhat, C.R. Schmitt, D. Bradley, M. Anderson, R. (2012). "**Comparison of Four-Step Versus Tour-Based Models for Prediction of Travel Behavior Before and After Transportation System Changes**". Transportation Research Board.	The paper compares the performance of four-step and tour-based models in predicting travel behaviour changes due to transportation system developments. Conducted within the context of three projects in the Columbus, Ohio, area, the study assessed model performance at both regional and project levels for specific years (1990, 2000, and 2005). The analysis focused on vehicle ownership, work trip distribution by time of day, and average work trip travel time. Results showed the tour-based model generally outperformed the four-step model across these dimensions. The study also included a detailed comparison of predicted link volumes from both models against observed link counts and roadway classes, but no clear trends emerged regarding model performance by class or year. This research aids in understanding the advantages and

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	limitations of different modelling approaches in transportation planning and forecasting.
Gemeente Utrecht. (?). **Marktconsultatie Gemeente Utrecht**. Utrecht: Gemeente Utrecht.	The document serves as a market consultation aimed at procuring a robust, scalable, and future-proof traffic modelling solution for a municipality. It addresses the complexities of modern mobility by focusing on Activity-Based Modelling and covers an extensive range of considerations including organisational vision, technological capabilities, data management, and information security. Additionally, it emphasises the importance of system compatibility and compliance with legal standards.
Helder, E. Bok, M. de, Jong, G. de, Verlinden, K. Puttemans, C. (2015). "**A review of theoretical and practical issues in microsimulating transport demand**". Paper presented at ETC 2015 in Frankfurt.	The paper discusses the advantages and problems of microsimulation in disaggregate travel demand modelling, emphasizing its application in the strategic passenger model for Flanders. It highlights the potential for simulation error, particularly in Monte Carlo simulation, and aims to understand and predict this error's statistical distribution to ensure accurate outcomes.
Hoeven, W. van der. (2019). "**Activity-based, agent-based,tour based: wat is wat, en hoe gebruiken we ze?**". TDIMCO.	The presentation describes the complexities and nuances of Activity-Based and Trip-Based Travel Demand Models. It examines their underlying assumptions, components, and data needs. While discussing the advantages and challenges, the presentation also raises questions about model validity, implementation time, and whether such detailed modelling is always necessary.
Huang, J. Cui, Y. Zhang, L. Tong, W. Shi, Y. Liu, Z. (2022). "**An overview of agent-based models for transport simulation and analysis**". Journal of Advanced Transportation 2022, Article ID 1252534: 1-17.	This article provides an overview of agent-based modelling in the context of transportation systems, focusing on recent developments, advantages, and existing gaps in the field. It begins by defining agent-based models, their development background, and their basic structure as applied to transportation systems. The discussion then moves to various agent-based transport modelling toolkits and their applications in transport systems, which are analysed using models based on three different time scales. Additionally, hybrid modelling approaches that integrate various time-scale models are explored. The paper also describes the in-depth modelling of individuals' beliefs, desires, learning, adaptability, and the optimization problems that can be addressed using agent-based models. However, it also identifies limitations in calibration and validation procedures,

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	modelling of agents' behaviour, and computational efficiency. The article concludes with recommendations for future research, highlighting potential and insightful directions such as the use of big data and Digital Twin technologies.
Kagho, G.O. Balac, M. Axhausen, K.W. (2020). "**Agent-Based Models in Transport Planning: Current State, Issues and Expectations**". In: Procedia Computer Science 170 (2020) 726-732.	Agent-Based models are powerful tools in transport planning, providing insights into complex human behaviours and interactions within transportation systems. The paper offers an overview of these models, discussing their development and application in transport planning. It highlights the problems faced by the agent-based modelling community and emphasizes the need for overcoming these hurdles to ensure the technique's continued relevance and efficacy in future transport planning endeavours.
Khorgami, S. Thitheridge, H. Jones, P. (2016). "**A conceptually innovative and practical approach to the modelling of household activities and travel behaviour**". Paper presented at ETC 2016 in Frankfurt.	The paper discusses the limitations of traditional trip-based travel forecasting models in capturing complex travel behaviours. It emphasizes the significance of activity-based models, which consider the broader context of daily activities. The paper aims to introduce a new modelling framework focusing on individual daily activities, addressing both in-home and out-of-home behaviours.
Kieu, L.-M. Malleson, N. Heppenstall, A. (2020). "**Dealing with Uncertainty in Agent-Based Models for Short-Term Predictions**". R. Soc. Open Sci. 7: 191074. DOI: 10.1098/rsos.191074.	This paper addresses the issues of dealing with uncertainty in agent-based models, specifically for short-term predictions. It highlights the difficulties in incorporating real-time data into these models to improve their predictive accuracy. The paper introduces a method combining parameter calibration and data assimilation techniques, allowing agent-based models to dynamically adjust to new data, thus increasing the reliability of short-term forecasts. This approach is explained through the modelling of a bus route system, illustrating how this methodology can account for the dynamic and stochastic nature of such systems. The paper contributes to the field by offering a framework that improves the accuracy of agent-based models in situations where system conditions are rapidly changing, making it particularly relevant for applications in urban traffic simulation and other dynamic systems.
Klein Kranenbarg, P. Brederode, L. Krol, L. (2023). "**Development of a microsimulation framework without statistical noise for tour-based demand modelling**".	This presentation outlines the development of a novel microsimulation framework designed to address the issue of statistical noise in tour-based demand modelling. The framework, named Octavius, is an advancement in strategic travel demand models,

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Presentation at the European Transport Conference 2023.	offering enhanced capabilities for transportation planning and analysis. The presentation begins with an introduction to the challenges of increasing complexity in strategic transport modelling and the need for more sophisticated simulation technologies. It discusses the limitations of traditional microsimulation approaches, particularly the issue of statistical noise, which can obscure the interpretation of results and reduce the reliability of predictions. The core of the presentation is the introduction of Octavius, a software framework that integrates various innovative techniques to overcome these problems. One of the key features of Octavius is the Statistical Noise Elimination Technique (SNET), which reduces statistical noise in the simulation outputs. The framework also incorporates QRIUS (Quenched Randomness In Utility Simulation), a method that enhances the stability and accuracy of the simulation results. The presentation details the technical aspects of these features and their application in the framework. The presentation highlights the current and future applications of Octavius in transportation research and planning. It emphasises the framework's potential to provide more accurate, reliable, and computationally efficient simulations for tour-based demand modelling. The development of Octavius represents a noteworthy contribution to the field of transportation modelling, offering a tool for analysing and predicting travel demand in complex urban areas.
Lemp, J.D. McWethy, L.B. Kockelman, K.M. (2007). "**From Aggregate Methods to Microsimulation: Assessing the Benefits of Microscopic Activity-Based Models of Travel Demand**". Transportation Research Record: Journal of the Transportation Research Board, No. 1994, Transportation Research Board of the National Academies, Washington D.C. pp. 28–37. DOI: 10.3141/1994-04.	This document explores the comparative advantages and efficacy of traditional aggregate travel demand models versus microscopic activity-based models. Utilising data from Austin, Texas, the authors contrast the two modelling approaches in various scenarios, including the base case, expanded capacity, and centralised employment. The paper underscores the enhanced sensitivity of microscopic models to changes in input data and policy interventions, illustrating their potential for more accurate and detailed transportation planning. Despite their complexity and increased demands for data and calibration, microscopic models provide nuanced insights into travel behaviours and are especially

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	effective in scenario analysis, a critical aspect of urban and transportation planning. The document concludes by stressing the necessity for further research to comprehensively understand the advantages and resource requirements of these advanced modelling techniques.
Miller, E. (2023). "**The current state of activity-based travel demand modelling and some possible next steps**". Transport Reviews, 2023, Vol. 43, No.4, 565-570.	The article discusses the gap between academic research and practical implementation in the field of travel behaviour modelling. While activity-based models have gained theoretical prominence, their adoption in operational planning is lagging, largely due to institutional conservatism and resource constraints. Additionally, the current state of practice is heavily inclined towards "tour-based" models, which have limitations in flexibility and scope. The article also points out that both existing tour-based and activity-based models are ill-equipped to adapt to new behavioural shifts, such as those induced by the COVID-19 pandemic. It calls for a more dynamic, theoretically sound approach, and advocates for collective action in sharing data and software to advance the field.
N.n. (-). **Short Notes on Agent/activity-based Modelling** (n.d.).	This document discusses agent-based and activity-based modelling in the context of transportation and travel behaviour analysis. Activity-based models address the limitations of trip-based models by incorporating the likelihood of an activity and the time budget for its duration. These models use either choice models or decision trees to modify activity, destination, and mode choices, leading to an Origin-Destination (OD) matrix for different times of the day. This OD matrix can be incorporated into traditional models or used in agent-based models like MATSim for near-continuous time simulations. However, in these agent-based models, agents (representing individuals) have predefined travel agendas and limited decision-making capabilities. The key feature of agent-based models is the ability of agents to interact with their environment, like choosing parking spaces or routes, but such details may not be necessary for strategic models. The document also outlines the technical requirements for running these models, such as 64-bit multicore machines with high RAM, command line interfaces for cloud operations, and the ability to generate synthetic populations. The document includes a literature list with references to various works on activity-based travel demand modelling, providing further context and details on this topic.

Reference	Summary
Nielsen, O.A. (2007). "**Trip-based route choice models - A method to eliminate aggregation bias in activity-based models**". Copenhagen: Technical University of Denmark.	The paper promotes the use of trip-based route choice models over traditional matrix-based models in transportation planning. It contends that trip-based models offer greater accuracy and detail by utilising individual trip attributes like Value of Time (VoT). These models allow for more consistent Level of Service (LoS) feedback into demand models, particularly beneficial for activity-based models. The paper also challenges the prevalent view that trip-based models are computationally intensive, arguing that they may be more efficient as models become increasingly complex.
Pinjari, A.R. Bhat, C.R. (2010). "**Activity-based travel demand analysis**". Austin: The University of Texas at Austin.	This document describes the evolution and importance of activity-based travel demand analysis within transportation planning. The transition from traditional supply-focused planning, centred on infrastructure development, to managing travel demand within existing transport systems, has increased the interest in activity-based models. Unlike trip-based models, which treat travel as a series of independent trips, activity-based models consider travel as a demand emerging from the need to participate in various activities. This approach provides a deeper understanding of travel behaviour, considering factors such as individual needs, preferences, social norms, and environmental characteristics.
Pougala, J. Tim Hellel, T. Bierlaire, M. (2021). "**Choice set generation for activity-based models**". Paper for 21st Swiss Transpotr Research Conference.	This paper explores the growing research interest in activity-based models over the past decade. AcBMs view travel demand as a result of individual activities and time-space constraints, offering a more flexible alternative to traditional trip-based models. The paper presents a Metropolis-Hastings-based methodology for efficiently sampling choice sets for econometric AcBMs, addressing the issue of handling combinatorial choices. The methodology is tested on Swiss Mobility and Transport data, laying the groundwork for future operational implementation in activity-based frameworks.
Rahnasto, I. Hollestelle, M. (2023). "**Increasing destination choice model accuracy of activitybased models with machine learning**". Paper presented at ETC 2023 in Milan.	The paper explores the efficacy of machine learning models in tour-based destination choice modelling, contrasting them with traditional discrete choice models like the multinomial logit. While conventional models offer interpretability, they may lack flexibility. The research finds machine learning promising in enhancing predictive power, albeit empirical evidence is limited.
Rasouli, S. Timmermans, H. (2013). "**Activity-based models of travel demand: promises, progress and prospects**".	The article explores the advancements and prospects of activity-based models in travel demand. These models, which have evolved significantly since their inception, offer a more nuanced understanding of travel

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International Journal of Urban Sciences. DOI 10.1080/12265934.2013.835118.	behaviour by considering the full pattern of individual activities and travel episodes. The authors discuss the initial goals of these models as an alternative to traditional four-step and tour-based models, emphasizing their increased sensitivity to a wide range of policy issues and improved consistency among sub models. The article reviews the progress made in the field, identifying ongoing issues and potential areas for further research. It underscores the importance of activity-based models in contemporary urban and transportation planning, highlighting their role in predicting the impact of land use and transportation policies on travel demand. The analysis suggests that while significant steps have been made, there is still room for improvement, particularly in addressing the complexities of short-term dynamics and individual-level decision-making in travel behaviour.
Romph, E. de . (2019). "**Activity-based Modelleren**". Delft: TNO 2019 M11385.	The note states that while initially more costly to construct than traditional models, Activity-based models for transportation planning have the potential to become more affordable and manageable as experience with them grows. Specifically, costs can be reduced by leveraging utility functions from existing projects. Advances in software and analytical tools are also anticipated to further decrease costs, although further development is still needed.
Rot M.C. (2015). "**A quantitative comparison of aggregate trip-based, disaggregate tour-based, and disaggregate activity-based travel production models**". MSc Thesis. Transport Infrastructure & Logistics (TIL). Delft University of Technology.	This MSc thesis focuses on comparing three different travel demand model approaches aggregate trip-based, disaggregate tour-based, and disaggregate activity-based models. The research aims to analyse the similarities and differences between these models in terms of their efforts and benefits, addressing a essential question in travel demand modelling why do people start travelling? The motivation behind this study is to enhance the understanding of the activity-based approach among transportation decision-makers, model developers, and academic institutions. The study is significant for bridging the gap between theoretical advantages of the activity-based approach and its practical implications, especially in the context of policymaking and technology. The research methodology involves a qualitative assessment based on literature review and the development of three production models representing

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	each approach. The study considers the entire four-step sequence of travel behaviour modelling, excluding the assignment step, as it is not deemed relevant for this comparison. Literature research reveals no theoretical difference in the resolutions at which the models operate. However, the main differences are found in the implications of the units of travel for behavioural realism. Data requirements vary among the models, with activity-based models demanding the most comprehensive data. This research uses the Dutch OViN survey to meet these data requirements. The development of the models is based on examples from model practice. The trip-based model uses the PADRE model as an example, requiring aggregated data about zone characteristics. The tour-based and activity-based models, using examples such as the Landelijk Model Systeem (LMS) and SACOG model respectively, require more detailed, disaggregated information. In assessing the outcomes, the study finds that while the trip-based model is relatively easy to implement and has shorter computation times, the tour-based and especially the activity-based models require more effort in terms of data preparation and parameter estimation. The activity-based model demands the most effort due to its comprehensive approach to capturing travel attributes. Quantitative assessment of the models shows that the activity-based model is the most accurate, with only a 2% deviation from the ground truth. The tour-based model follows with a 6% deviation, and the trip-based model has a 15% deviation. However, the activity-based model requires significantly more development effort, pointing to a trade-off between accuracy and resource investment. The study concludes that the performance of an activity-based production model is closely related to the model's purpose, with its high accuracy being a key advantage.
Stabler, B. (2023). "**Lessons learned from 15 years of building ABM software**". Paper presented at ETC 2023 in Milan.	The presentation outlines 15 years of experience in building activity-based models for transport planning. It emphasises the importance of a robust, user-centric software platform for sustained application. Lessons learned include the need for real-world test examples, the balance between behavioural design and efficiency,

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	computational issues, and the significance of a large user community for ongoing development.
Tajaddini, A. Rose, G. Kockelman, K.M. Vu, H.L. (2020). "**Recent Progress in Activity-Based Travel Demand Modeling: Rising Data and Applicability**". In: Models and Technologies for Smart, Sustainable and Safe Transportation Systems - IntechOpen.	Over the past 30 years, activity-based travel demand models (AcBMs) have evolved to address the shortcomings of previous models used for over 50 years. AcBMs detail household and individual travel choices, offering more accuracy in transportation planning. This paper reviews current AcBM practices, highlighting improvements in capturing behavioural realism. It emphasizes the potential of integrating new data sources, like mobile records and GPS, for enhanced modelling and discusses the transferability of these models for diverse geographical and policy contexts.
VDOT. (2009). "**Implementing Activity-Based Models in Virginia**". Chapter 2, Transportation Models: A Brief Comparison. VTM Research Paper 09-01.	This document addresses the implementation of activity-based models in transportation planning in Virginia. It contrasts these models with the prevalent four-step models used by the Virginia Department of Transportation (VDOT). VDOT's approach advocates for cost-effective models that meet transportation planning needs and policy directions, emphasising updates based on recent survey data and planning assumptions. The main advantage of activity-based models is their potential to address some limitations inherent in conventional models. However, the document also highlights theoretical drawbacks, including questions about the assumptions of these models and the feasibility of realising their anticipated benefits. An important aspect discussed is the cost comparison between developing and maintaining advanced four-step models versus activity-based models. For smaller and medium area models, the estimated five-year cost ranges from $2.1 to $2.8 million for advanced four-step models, compared to $5.3 to $5.9 million for activity-based models. In larger area models, the cost is projected to be $2.0 to $2.8 million for advanced four-step models over the same duration. This cost analysis underscores the substantial financial considerations involved in adopting activity-based models in Virginia's transportation planning.
Vovsha, P. Vyas, G. Florian, D. Florian, M. (2019). "**Road Map for Gradual Improvements of Travel Models – From 4-step to Agent-Based**". INRO.	This presentation outlines a roadmap for the gradual improvement of travel models, from traditional 4-step models to advanced Agent-Based Models (AgBM). It discusses various model types and their evolution, emphasizing the transition from aggregate models to more sophisticated, individual-level approaches.

Reference	Summary
Willumsen, L. (2023). "**Activity-based Models**". Transport Planning Demand Modelling and Forecasting. LinkedIn article.	This post introduces a shift in transportation modelling towards a more realistic understanding of travel behaviour. It emphasizes that travel is a means to engage in various activities at different locations and over time. The focus is on interconnected activities rather than isolated trips, leading to the development of Activity-Based Models (AcBMs) and Agent-Based Models (AgBMs) that require a granular approach and synthetic population generation to represent individuals and households in transport modelling.
Willumsen, L. (2023). "**Agent-based Modelling in Transport**". Transport Planning Demand Modelling and Forecasting. LinkedIn article.	Agent-based modelling (AgBM) in transport is a computational method for simulating the behaviour of individual agents (such as humans, vehicles, or other entities) and their interactions within a system. This approach has gained popularity in traffic and transportation modelling, allowing for a more nuanced understanding of traffic systems and the development of effective transportation policies. In traffic microsimulation, for example, agents are vehicles with specific characteristics like speed and acceleration, which interact on roads to mimic real-world traffic scenarios. This modelling helps compare the performance of different road geometries and traffic control systems.
Willumsen, L. (2023). "**Population Synthesis and Models**". Transport Planning Demand Modelling and Forecasting. LinkedIn article.	This document focuses on the development of synthetic populations for use in transport planning and demand modelling. The primary goal is to assess the distributional impacts of transport interventions and reduce inequalities in access to opportunities. The process of creating a synthetic population involves using data from travel surveys and census data to represent the demographic distribution in a study area accurately. This population is then used in various modelling approaches, such as Agent or Activity-Based Modelling, to forecast future scenarios and test policies. The synthesis procedure includes estimating the demographic distribution of households in each transport zone, followed by an iterative multi-proportional fitting procedure to match household data with census information. Additional characteristics, like car ownership and household composition, can be integrated into the models. The process also entails identifying individual attributes within households and assigning precise geographic locations to each household for detailed modelling. This synthetic population is important for detailed analysis of transport interventions, providing a comprehensive picture of the population's characteristics and

Reference	Summary
	behaviours in relation to transport planning and demand forecasting.
Zill, J.C. Veitch, T. Vuren, T. van. (2022). "**Comparison of policy scenarios with trip-based and econometric activity-based models**". Paper presented at ETC 2022 in Milan.	The study compares trip-based and activity-based models for transport planning in the Greater Brisbane area. Both models exhibit similar high-level outcomes, but the activity-based model offers more nuanced results, including peak period spreading. The research also addresses the theoretical foundations of ActivitySim, highlighting implications for economic benefit analysis.
Zondag, B. Vovsha, P. Scherr, W. Canella, O. Teye, C. (2023). "**Discussion on activity-based Models and agent-based Models**". Transcript of session on activity-based models at ETC 2023.	This discussion explores the differences, implications, and challenges of activity-based models and agent-based models in transportation planning. AcBMs focus on modelling individual trips and activities, while AgBMs offer a holistic view of interactions among agents. Challenges include data access, computing power, client awareness, and policy alignment, but both models offer rich data and flexibility for modern transportation planning.

Annex 3 Findings from the literature

What can be found in the literature on activity-based and agent-based models? What topics are discussed in the literature? What themes are relevant for the inventory? These and other questions are addressed in this annex.

3.1 Introduction

To answer part of the questions, we carried out a desk-research. This mainly involves literature searches. We collected books, articles, presentations, and columns from the following sources:

- Google Scholar, Elicit.org, ResearchGate.net.
- Recent papers presented at ETC and CVS in the last three years.
- Other literature available from Panteia, SIVMO, governments, market players and knowledge institutions.

We only collected publicly available information, that is articles, papers, and reports in PDF format. This led to a total of more than 300 sources. The complete list is given in Annex 1. This list is made accessible for SIVMO.

We acknowledge the fact that there is more literature than we have considered. Paid literature for example, has been only considered partially. This may have left us with some unexplored sources. But within the framework of this project, we feel that the available sources gave us sufficient insights to provide a first base to answer the questions at stake and to carry out the interviews and workshop.

This annex reviews the literature and provides *observations* in the first place. No direct conclusions or recommendations are drawn here. Since we look at themes, sometimes information is duplicated.

3.2 Main themes in the collected literature

From the collected literature, we distilled key themes. These show a multidimensional approach to current and future challenges in modelling for urban transport and mobility planning. The main themes from the collected literature are:

- *Hybrid modelling approaches*. Development of methods that combine features of both macroscopic travel-based models and microscopic activity-based models, creating more realistic and comprehensive mobility plans. An example includes Polak (1999).
- *Integration of big data in transport modelling*. The integration of large-scale data sources, such as mobile phone, into transport demand models represents a significant advance. This integration enriches models with real-time data, increasing their accuracy and reliability. Examples include Anda et al (2016), Bassolas et al (2018), Franco et al (2020), Long et al (2009) and Wu et al (2019).

- *Sustainability in urban transport*. Focus on models that help decarbonise urban transport, promote sustainable mobility solutions and understand the impact of different interventions on greenhouse gas emissions. Examples include Alvarez et al (2022), Krajewicz et al (2019), Krishnapriya et al (2019), ter Laag (2019), Sommer et al (2022) and Wörle et al (2021).
- *Synthetic population for activity-based modelling*: References in this theme explore techniques for generating and assigning synthetic populations, especially in the context of spatial planning and transport modelling. Creating synthetic populations is important for simulating realistic urban areas and understanding population dynamics. Examples include Agriestie et al (2022), Barthelemy et al (2012), Brederode et al (2013), Joemmanbaks et al (2021), Wise et al (2017).
- *Advances in simulation platforms*. The evolution of integrated simulation platforms at multiple scales that encapsulate different behavioural models in a unified framework. See, for example, Davidson et al. (2011), Mastio et al. (2018), Lu et al. (2014) and Zegras et al. (2016).
- *Activity-based demand modelling*. This theme represents a paradigm shift towards activity-based models that consider the full spectrum of household and individual activities and associated travel patterns. This shift enables more accurate predictions of urban travel demand by capturing the nuances of daily life. References include Bowman et al (2005), Clarke et al (2008), Hao et al (2016), McNally et al (2008), Miller (2023), Polak et al (1999) and Rahnasto et al (2023).
- *Agent-based models in policy analysis*. Use of agent-based models to simulate, analyse and evaluate urban transport policies, especially in the context of sustainable mobility and infrastructure planning. This theme provides a few relevant references for the inventory. Examples of references for this theme include Arup (2023), Maggi et al (2016), Zhang et al (2004), and Zhou et al (2023).
- *Spatial portability and model reinstatement*. Investigating the spatial portability of models such as ALBATROSS in different geographical contexts and the reinstatement of models using updated datasets. See, for example, Arentze et al. (2002), Arentze et al. (2003), ter Laag (2019), Tajaddini et al. (2020), and Ziemke et al. (2019).
- *Household interactions in travel behaviour*: Investigating how household dynamics, including joint activity participation and resource allocation, affect travel behaviour and demand modelling. See Anggraini et al. (2009), Arentze et al. (2003), Bazzan et al. (2009), van Bladel (2009), Khorgami (2013), Martinez et al. (2017) and Recker (2000).
- *Innovations in activity-based and agent-based frameworks*. Exploration of new methodologies and improvements in activity-based and agent-based modelling frameworks, aimed at their application in various urban contexts and for various mobility-related issues. Examples include Calvacante et al (2013), Kim et al (2021), Viegas de Lima et al (2018), Zargayouna (2021), and Zill et al (2022).

Together these themes emphasise integrating advanced data sources, sustainability considerations and innovative modelling techniques to create a holistic and dynamic understanding of urban transport and mobility planning. Based on the literature, we selected several references that together could potentially answer the research questions at stake.

3.3 Findings from selected references

The selected references provide an overview of various topics related to activity-based and agent-based models in the context of transport planning and modelling. The main themes include:

- Transition from traditional to activity- and agent-based models.
- Challenges and opportunities in model implementation.
- Cost considerations in developing and maintaining models.
- Technological advances.
- Behavioural realism and model validation.
- Specific applications and case studies.
- Future research directions.

These themes highlight the shift towards more sophisticated modelling approaches in transport planning, aimed at capturing the complex nature of travel behaviour and improving the planning and implementation of transport systems.

3.3.1 Transition from traditional models to activity-based models

The transition from traditional to activity-based (AcBM) and agent-based models (AgBM) in transport modelling represents a change in understanding and analysing travel behaviour. This is due to the shortcomings of traditional models, which often capture the complexity of individual travel choices and the dynamics of transport systems in simplistic terms. Traditional models, such as the trip-based models, are criticised for not adequately reflecting the reality of travel behaviour and therefore not accurately reflecting the impact of transport policies and infrastructure adjustments.

As modelling shifts to AcBMs and AgBMs, the need for detailed travel behaviour data, advanced computing resources and sophisticated software tools becomes more apparent. This is motivated by the potential that AcBMs and AgBMs offer for transport planning, policy analysis and system management. These models provide a more detailed perspective and model the activities and interactions of individual agents in the transport system. This makes it possible to thoroughly investigate how individuals' travel decisions are affected by various factors, including policy initiatives, infrastructure changes and the advent of new mobility services.

However, according to the selected references, the transition is not free of challenges. The development and implementation of AcBMs and AgBMs are characterised by significant resource intensity and require significant financial investment, time and expertise for development, calibration, and maintenance. Despite these challenges, the shift is driven by the expected benefits these models offer over traditional approaches, including improved accuracy in transport planning and the capacity to test and analyse the effects of different policies and changes within the transport system.

References provided that refer to the different facets of this transition include:

- Brederode (2023) focuses on the transition from macroscopic trip-based models to microscopic tour-based models and discusses the challenges and opportunities this shift presents.

- Castiglione, Bradley and Gliebe (2015) provide an introductory exploration of activity-based models (a primer) and highlight their role in replicating real traveller decisions.
- Chu, Cheng and Chen (2012) provide an overview of developments in activity-based travel demand models, focusing on the shift towards behavioural AcBMs.
- Vovsha, Vyas, Florian and Florian (2019). They outline a strategic plan for the transition from four-step to agent-based models, detailing the necessary steps for this progress.
- Willumsen (2023) explores the specifics of AcBMs and AgBMs and discusses their theoretical underpinnings and their application in transport planning in 2 LinkedIn articles.

These references highlight the rationale behind the move towards more sophisticated modelling approaches and illustrate a broader trend towards more detailed and realistic modelling of travel behaviour in transport planning.

3.3.2 Challenges and opportunities

The references on challenges and opportunities in modelling implementation shed light on the complexity of the shift towards more sophisticated transport modelling techniques, such as activity-based (AcBM) and agent-based models (AgBM). This evolution represents a shift from traditional, less detailed models to approaches that can more accurately reflect the complexity of actual travel behaviour. However, this shift introduces challenges and opportunities that are essential for the successful implementation of these models in transport planning.

One of the main issues concerns the significant data requirements and computing power needed for AcBMs and AgBMs. These models rely on detailed data on households and individual travel behaviour and interactions, which requires extensive data collection and powerful computing infrastructure. In addition, the complexity of these models can raise issues of model calibration and validation to ensure that the models accurately reflect observed travel patterns.

Despite these issues, the shift towards AcBMs and AgBMs offers substantial opportunities for improving the accuracy and relevance of transport models and their use in underpinning policy questions. These models offer a more nuanced understanding of travel behaviour, making it possible to analyse how individual decisions are affected by various factors, including changes in transport policy, infrastructure, and services. This level of detail is particularly valuable for addressing transport planning challenges, such as the need to offer new mobility services and the step towards more sustainable transport systems.

The references also highlight the importance of technological developments to facilitate the application of AcBMs and AgBMs. Developments in data collection technologies, such as location data from mobile phones and connected vehicle data, offer new opportunities for collecting the detailed behavioural data needed for these models. Advances in computing power and software tools are also making it increasingly feasible to develop and run complex models.

References supporting this theme illustrate a range of perspectives on the challenges and opportunities presented by AcBMs and AgBMs.

- Bastarianto et al (2023) provides a comprehensive overview of agent-based models in urban transport, identifying research gaps and potential directions for future research.
- Bazzan and Klügl (2013) discuss the application of agent-based technologies in traffic and transport engineering and highlight their role in addressing the complexity of transport systems.

Although the transition to activity- and agent-based models in transport planning comes with challenges, it also offers opportunities to significantly improve the accuracy and applicability of transport models. These models have the potential to provide more detailed and realistic insights into travel behaviour to support more effective transport planning and policy making.

3.3.3 Cost considerations in developing and maintaining models

The references on cost considerations in developing and maintaining models, address the financial aspects involved in introducing activity-based models and agent-based models. They highlight the investments required not only for the initial development of these models, but also for their maintenance and calibration. The detailed insights that AcBMs and AgBMs provide into the travel behaviour of individuals and households involve higher costs related to data collection, processing and calculation compared to traditional models.

An important element is the comparative analysis of costs between developing and maintaining advanced four-step models versus activity-based models. According to VDOT (2009), estimated five-year costs for transport models for smaller and medium-sized areas range from $2.1 to $2.8 million for advanced four-step models, while costs for activity-based models are estimated at $5.3 to $5.9 million. This difference in cost highlights the importance of careful planning and trade-offs when choosing to implement AcBMs. Caution should be exercised as this reference is from 2009 and may differ significantly from current practice concerning costs in the Netherlands. However, it can give a first impression of the costs involved.

Stabler (2023) highlights experiences and insights from 15 years of AcBM software development. His presentation offers a look at the practical challenges and solutions encountered in the development and application of AcBM software for transport planning, and highlights the need for robust, user-friendly software platforms for effective long-term use. Stabler emphasises the balance needed between behavioural realism, computational efficiency, and the importance of a large user community to continuously improve the software.

Tajaddini et al (2020) describe the improvements in behavioural realism and the integration of new data sources such as mobile phone and GPS for improved modelling. This reference also looks at the transferability of the models in different geographical and policy contexts, providing a broader view of the applicability and cost-effectiveness of AcBMs. Transferability of transport models has been applied in The Netherlands as well.

Concerning costs in general we can conclude that although the costs of AcBMs and AgBMs are higher than that of traditional models, their ability to deliver more accurate, detailed, and policy-responsive analyses of travel behaviour can justify the investment. Moving to these advanced models requires a strategic approach to cost management, with the aim of maximising the benefits they provide for sound transport planning and policy formulation.

3.3.4 Technological advancements

References to technological advances focus on the integration of machine learning techniques and other technological innovations within the development and refinement of transport models, especially activity- and agent-based models. They highlight the impact of these developments on improving the precision, efficiency, and applicability of models to address complex transport and mobility questions.

An important aspect is the use of machine learning to improve the predictive accuracy of transport models. The application of machine learning algorithms enables improvement in the accuracy of choice models within AcBMs, as illustrated by Rahnasto et al. (2023). This reference represents progress towards models that more accurately represent human mobility patterns and preferences. Research by Pougala, Hellel and Bierlaire (2021) on modelling travel-based destination choices using machine learning provides a comparison between traditional discrete choice models and machine learning approaches. It highlights the potential of machine learning to improve model adaptability and predictive capacity, although current empirical evidence is somewhat limited.

Other advances represent a broader shift in the field towards using big data and computational techniques to effectively capture the complexity of travel behaviour. These advances are important for improving transport models that can accurately predict human mobility, making transport planning and policy-making more accurate.

The references highlight a shift towards models that are increasingly data-driven, more precise, and able to adapt to the rapidly changing dynamics of transport systems and technologies. This evolution brings opportunities and challenges, such as the need for advanced data management skills and continuous development of computational methods, to exploit the potential of these advances in transport modelling.

3.3.5 Behavioural realism and model validation

References on behavioural realism and model validation (including calibration) address the aspect of ensuring that transport models accurately represent real-world travel behaviour and the methods used to validate these models. This is important for the development of AABMs, which should provide a more refined understanding of travel patterns and decision-making processes for travel choices.

Behavioural realism in transport models is about reproducing the complexity of human travel behaviour, including the decision processes underlying travel choices, such as mode choice, destination, and time of day. This realism is important to predict travel demand, as well as the impact of transport policy and infrastructure changes. Davidson (2007) and Bekhor (2014) highlight efforts to improve realism in models by including detailed data on activities and travel behaviour and using advanced modelling techniques that can consider the multifaceted nature of travel decisions.

Model validation and calibration is another aspect, which focuses on verifying model outputs against observed data to ensure the predictive accuracy of the models. Validation techniques often include comparing modelled travel patterns with actual data from travel surveys or traffic counts. This is important for the credibility and reliability of models as tools for transport planning and policy analysis. It shows the importance of validation that can assess the quality of models on characteristics, such as their ability to replicate observed travel behaviour and to realistically respond to changes in transport systems.

References on behavioural realism and performing model validation include:

- Bekhor (2014) presents an analysis of the stability of activity-based models and the challenges in achieving model convergence and dealing with the randomness in individual travel behaviour.
- Drchal, Certický and Jakob (2015) introduce a validation framework for multi-agent activity-based models that uses historical real-world data to assess the validity of these models.
- Davidson et al. (2007) provides practical examples of activity-based travel demand modelling, highlighting the conceptual advantages of these models and the practical issues related to their implementation and validation.

These references highlight efforts to improve the realism and validation of transport models, reflecting the broader goal of developing tools that can accurately simulate current and future travel behaviour and effectively inform transport planning and policy decisions.

3.3.6 Specific applications and case studies

Several references describe the application of activity-based and agent-based models in various scenarios and highlight the innovative methodologies and practical benefits of using these models in transport planning and policymaking. They highlight a variety of studies that provide insights into the implementation of these models and show the broad spectrum of applications, from strategic planning to behavioural analysis. The references cover a wide range of contexts and geographical locations and illustrate the versatility and effectiveness of AcBMs and AgBMs in addressing contemporary transport questions.

Key references supporting this theme include:

- Brederode L. (2023) explores the transition from macroscopic to microscopic models in the Netherlands and highlights the shift to micro-modelling driven by changes in mobility patterns, particularly the shift from possession to use (shared mobility).
- Canella O., Engelson L., Berglund S. (2023) investigate the influence of stochastic elements in microsimulation within a Swedish context and offer insights into the variability of infrastructure project assessments.
- Davidson W.A., Donnelly R., Vovsha P., Freedman J., Ruegg S., Hicks J., Castiglione J., Picado R. (2007) explore operational research approaches and best practices in activity-based modelling.
- Miller E.J., Roorda M.J. (2003) introduce a prototype model focusing on planning household activities and travel and show early application of activity-based approaches.

- Pendyala R.M., Bhat C.R., Guo J.Y., Astroza S., Sidharthan R., Goulias K.G., Sana B. (2012) describe an econometric micro simulator designed to predict daily activity-travel patterns, illustrating the use of econometric techniques in activity-based modelling.

These references describe developments in transport modelling, with traditional approaches being improved or replaced by more detailed and realistic modelling techniques. Using case studies and research efforts, the references show the role that AcBMs and AgBMs play in advancing our understanding and capabilities in planning the future of transport systems.

3.3.7 Future research directions

The references on future directions in transport modelling anticipate the evolution of methodologies. These future-oriented perspectives emphasise the integration of innovative data sources, the application of new technologies and the development of methodologies to improve the realism, efficiency, and applicability of models to address current and future mobility questions.

Recent references include:

- Bastarianto F.F., Hancock T.O., Choudhury C.F., Manley E. (2023) with a comprehensive review identifying research gaps and future directions, focusing on the need for advances in computational efficiency and model calibration.
- Huang J., Cui Y., Zhang L., Tong W., Shi Y., Liu Z. (2022) provide a thorough review of recent developments in agent-based modelling, highlighting both benefits and issues in the field.
- Kagho G.O., Balac M., Axhausen K.W. (2020) discuss the application of agent-based models in transport planning, highlighting the challenges and the need to overcome them to maintain the relevance of the technique.
- Kieu L.-M., Malleson N., Heppenstall A. (2020) discuss the challenges of incorporating real-time data into agent-based models to improve forecast accuracy, especially for short-term forecasts.
- Klein Kranenbarg P., Brederode L., Krol L. (2023) introduce a microsimulation framework that addresses statistical noise, representing a significant advance in strategic travel demand models.

These references point towards a future in which transport modelling becomes increasingly dynamic, data-driven, and increasingly able to capture the interplay between travel behaviour, technological advances, and mobility trends.

3.4 Conclusions

The exploration of literature on activity- and agent-based models has highlighted their role in improving our understanding of travel behaviour. These models offer great potential to explore the dynamics of individual and collective travel behaviour, enabling more detailed and predictive analysis of transport policy and infrastructure planning. However, according to the literature, the transition to these advanced model frameworks requires considerable computing power and advanced data processing capabilities.

Despite these issues, the potential benefits in terms of improved accuracy, improved underpinning of policy measures concerning travel behaviour, and the ability to integrate sustainability into transport planning are significant. Research focuses on solving various technical and methodological problems associated with these models, including integrating real-time data, introducing machine learning, developing more user-friendly model simulation platforms, and improving model portability in different contexts.

Activity-based and agent-based modelling introduce new ways for urban, regional, and national transport research and policy analysis in the Netherlands. By introducing these approaches, researchers, policymakers, and planners may gain deeper insights into the complexity of travel behaviour in relation to policy measures. This potentially leads to more effective and sustainable transport solutions. As technology and data availability continue to evolve, there is a need to embrace these developments and ensure that transport systems are resilient, efficient, and aligned with broader environmental and societal goals.

Annex 4 Findings from the interviews

What are the views of experts on activity-based and agent-based models? How do they see aspects such as stochasticity? How do they develop, implement, and apply activity-based models? These and other questions were addressed in the interviews. This annex provides a summary of the most important topics discussed.

4.1 Introduction

This annex presents a summary of observations from interviews with international experts in the field of AABMs. Through these discussions, different topics were explored, including definitions, methodologies, data requirements, as well as the benefits and problems of deploying these advanced modelling techniques. The interviews include both Dutch and global experiences and insights that shed light on the state of transport modelling. By looking at the different perspectives of the experts, this annex offers an examination of both the technical details and practical considerations involved in the development, maintenance, and application of AABMs in different environments.

It is important to note that this annex is *structured around the observation of themes* that emerged from the interviews, rather than drawing conclusions from the interviews. The interviews showed a broad spectrum of themes, reflecting the diverse expertise and views of the interviewees, including, but not limited to, methodological approaches, complex data, partnerships, policy implications, applications, and future developments in the field. These observations serve as a basis and provide an overview of the multifaceted nature of AABMs, the collaborations within the field of modelling, and the developments in transport modelling. This annex aims to provide a broad understanding of the current and future potential of AABMs.

The following themes are further elaborated in the next sections of this annex:

These themes show the complexity and dynamic nature of AABMs, highlighting their potential for transport planning and policy analysis. The interviews provide an overview of current practices, problems, and prospects in the field of transport modelling, reflecting a consensus on the need for continuous innovation and adaptation in model development and application.

4.2 Context and definitions

The context and definitions of AABMs are fundamental to understanding the nuances and applications of these modelling approaches for transport planning and policy analysis. This topic explores the theoretical frameworks, methodological differences, and the terminology that distinguish activity-based models (AcBMs) from agent-based models (AgBMs), paving the way for their practical implementation and integration into transport studies.

4.2.1 Theory and definitions

Theoretical underpinning. Activity-based models (AcBMs) are based on the theory that the demand for transport is derived from the activities in which individuals and households participate during a day. Unlike traditional trip-based models that focus on trips as stand-alone events, AcBMs consider the sequence of activities, the context in which they take place, and the interdependence between the activities of individuals within a household. This approach provides a better understanding of travel behaviour, as it is recognised as a 'by-product' of lifestyle choices, social interactions, and economic constraints.

Agent-based models (AgBM), while similar in abbreviation (ABM), and sharing conceptual overlap with AcBMs, extend the modelling approach by simulating the interactions between individual agents (representing people, households, or other entities) and their environment. These models include decision-making processes, adaptation to changing conditions, and interactions between agents, allowing the examination of complex systems and emergent behaviour within a simulated environment. According to the strict definition of AgBMs, these models are self-learning, although this is not commonly agreed upon between the experts.

Methodological differences. The distinction between activity-based and agent-based models is significant and reflects the different focus and capabilities of each approach. Activity-based models focus on predicting activity patterns and the resulting demand for transport, using detailed data on individuals' activity participation, timing, and location choices. These models often use sophisticated algorithms to simulate the decision processes associated with activity participation and travel choices.

Agent-based models emphasise the simulation of individual agents and their interactions within a defined system in a self-learning way. These models are particularly good at capturing phenomena arising from the interactions of multiple agents, making them suitable for studying complex systems where individual behaviour and interactions lead to collective outcomes. Agent-based models are flexible, can integrate different behavioural theories, and can simulate a wide range of scenarios, including those involving non-traditional transport modes and services.

Terminological clarity. The distinction in terminology between activity-based and agent-based models is important. While both models simulate the behaviour of individuals within a transport system, the term "activity-based" is used specifically to refer to models that focus on activity-based transport demand prediction. In contrast, "agent-based" models refer to a broader class of models that simulate individual agents and their interactions in a self-learning way. This can be applied not only to transport, but also to economic systems, social networks, and ecological systems.

Understanding this distinction is essential for researchers, policymakers, and practitioners when experiencing the complexity of transport modelling. The distinction helps in choosing the right modelling approach based on the research question or policy need and ensures that the chosen model is the most appropriate to capture the dynamics and interactions of interest.

4.2.2 Conclusion

The context and definitions of AABMs underscores the importance of understanding the theoretical foundations, methodological approaches, and precise terminology. This understanding is essential for promoting the strengths of each modelling approach to effectively address complex transport planning and policy questions.

Activity-based models focus on understanding travel demand stemming from individuals' daily activities, considering the location, duration, and purpose of these activities. They provide a detailed simulation of travel patterns by examining how these activities influence travel decisions and behaviour.

Agent-based models simulate the interactions of autonomous agents (such as individuals or vehicles) with each other and their environment, incorporating the capacity for agents to learn and adapt based on their experiences.

4.3 Methodological issues

4.3.1 Methodological challenges and solutions

The interviews covered the technical challenges encountered in the development, validation, calibration, and reproducibility of AABMs. This comprised a range of topics, from managing stochasticity in simulations to the allocation of computational resources and addressing the complexity involved in simulating transport demand and flows. These challenges must be overcome to improve the reliability, accuracy, and applicability of AABMs for transport planning and policy analysis.

General technical challenges in model building

Complexity of AABMs. One of the main points is the complexity of AABMs, which stems from their detailed representation of individual and household behaviour. Ensuring that these models represent realistic scenarios requires calibration and validation with observed data. This process is complicated by the multifaceted nature of human mobility patterns and interdependencies within the transport system.

Complexity versus computability. The search for an accurate simulation of human mobility often leads to highly complex models that can push the limits of computation. Strategies to manage stochasticity while preserving model detail must also consider the practicalities of using models, including computational efficiency and the ability to interpret and apply results to real-world scenarios.

Integration of different data sources. Integrating different data sources to create a coherent, representative model is another key topic. This includes population synthesis, activity and travel diaries, land use information and network characteristics into a unified model framework. Achieving a balanced representation that captures the variability between different population segments and geographical areas is important for the validity of the model.

Solutions and strategies

Advanced computational techniques. The deployment of advanced computational techniques, including cloud computing, can alleviate some of the computational issues of AABMs. These technologies enable the processing of large datasets and complex model simulations, reducing computation time and increasing model scalability.

Model modularisation. Modularisation is a strategic approach to manage the complexity of models. Modularisation of model components enables incremental development and testing, which facilitates calibration and validation. This approach also supports isolating specific modules for detailed analysis or updates, which improves model adaptability and maintainability.

As an example, a population synthesis can be developed first and then use it in the application of a transport model (even traditional ones). In a next step we include other components such as an activity scheduler. A population synthesis developed at a national level can be used in different urban and regional transport models.

Innovative validation techniques. The use of innovative validation techniques, such as cross-validation with independent datasets or the use of virtual environments for testing models, can improve the robustness of AABMs. These methods help assess the predictive accuracy of the model and its ability to replicate observed behaviour under different conditions.

Reproducibility and open science practices. Ensuring the reproducibility of AABMs is essential for their usefulness in the scientific community and with policymakers. Adopting open science practices, including sharing data sources, model source codes and simulation results, can facilitate peer review and collaborative refinement of models. Documentation of the modelling process and the establishment of standards for sharing data and codes are also vital for promoting transparency and reproducibility.

Addressing the methodological issues of AABMs requires a combination of advanced computational methods, modularisation of models, validation approaches and a commitment to the principles of open science. These strategies not only reduce the technical hurdles associated with modelling, validation, and reproducibility, but also enhance the usefulness of AABMs as tools for informed decision-making in transport planning and policy development.

4.3.2 Handling stochasticity and model complexity

The discussions on stochasticity and model complexity address the complexity within the models and the strategies used to manage the inherent randomness, with the aim of ensuring reproducible and reliable outcomes. Stochasticity, or the randomness in decision-making and behavioural patterns, is a key point of attention in modelling as it affects the reproducibility, predictability, and consistency of model results. Addressing these topics requires a careful trade-off between preserving the detailed representation of complex human behaviour and ensuring that models remain computationally feasible and practically applicable.

Managing stochasticity in models

Stochasticity in transport modelling. The stochastic nature of human mobility - in which individuals make unpredictable choices about when, where, and how to travel - requires models to incorporate randomness to accurately reflect actual behaviour. However, uncontrolled stochasticity can lead to variability in model outcomes, making it difficult to reproduce results and draw reliable conclusions from simulations.

Dealing with stochasticity. Managing this stochasticity to ensure consistent, reliable predictions requires sophisticated modelling techniques. Approaches such as Monte Carlo simulations or the use of seed values in generating random numbers can help address this issue, by exploring a range of possible outcomes and enabling the quantification of uncertainty.

Super sampling. Super sampling is a technique designed to mitigate the effects of stochasticity by increasing the number of simulated entities or scenarios beyond the typical or expected sample size. This approach aims to capture a wider range of behaviours and outcomes, smoothing out deviations and reducing the impact of random variation on model results. Super sampling improves the robustness of model predictions but also requires more computing power or time, requiring a balance between detail and practicality.

Semi-stochastic procedures. Semi-stochastic procedures comprise methods for generating quasi-random numbers, provides a way to introduce controlled randomness into models. Quasi-random sequences such as the Halton sequence are designed to cover the sample space more uniformly. This ensures that the stochastic elements of the model are distributed in a more predictable and evenly spaced manner, reducing the variance between simulation runs and improving the reproducibility of the results. The use these techniques allows modellers to include stochastic processes while maintaining a degree of control over randomness, ensuring more consistent outcomes.

Application of techniques. The application of techniques such as super-sampling and the Halton sequence requires careful consideration of the objectives of the model and the specific challenges posed by stochasticity. For example, in scenarios where accurate estimation of demand variations is important, super-sampling may be prioritised despite the greater computational burden. Conversely, in models where uniform coverage of the sample space is more important, semi-stochastic procedures may be preferred to ensure consistency and reproducibility.

Conclusion

Dealing with stochasticity in transport modelling requires a nuanced approach, employing advanced techniques to ensure reproducible results while maintaining the richness and depth of simulated behaviour. The strategic use of super-sampling and semi-stochastic procedures illustrate the ongoing efforts to achieve a balance between capturing the intricacies of human mobility and ensuring that the models remain tailored to practical applications.

4.3.3 Model comparison and model integration

In the interviews we compared AABMs with traditional models in transport planning and policy analysis. This comparison sheds light on the distinctive advantages of AABMs, particularly in terms of their ability to integrate demand generation with simulation of traffic flows. Moreover, it highlights the points of attention involved in improving the usability and computational efficiency of these models, especially when applied to large-scale simulations.

Comparative advantages of AABMs

Improved representation of behaviour. AABMs provide a better representation of individual and household behaviour compared to traditional models, which often rely on aggregate assumptions and simplified decision-making processes. By simulating the sequence of activities and choice processes of individuals, AABMs provide insight into the underlying factors that determine travel demand and mode choice. This detailed behavioural modelling provides a deeper understanding of the dynamics of transport and enables the investigation of policies aimed at influencing individual travel choices.

Integration of demand generation and traffic flow. One of the strengths of AABMs lies in their ability to seamlessly integrate demand generation with simulation of traffic flows (such as ActivitySim). This integration makes it possible to simultaneously examine how changes in transport policy or infrastructure investment affect travel behaviour, demand patterns and transport network performance. Traditional models often treat demand generation and traffic flow as separate components, which can limit their ability to capture the interactive effects between demand-side changes and supply-side responses.

Flexibility and adaptability. AABMs are flexible and adaptable, allowing them to incorporate new transport modes, technologies, and services. This adaptability is especially important in the context of urban mobility, where new transport modes and technological innovations (such as car-sharing, MaaS, e-bikes) are constantly changing travel patterns. Traditional models may struggle to accommodate these dynamics because of their more rigid structure and assumptions.

Challenges in model integration and usability

User-friendliness. Despite their advantages, AABMs can be challenging for practitioners to use, mainly due to their complexity and the knowledge required to use and interpret the models. Improving the usability of AABMs, through the development of intuitive interfaces and comprehensive documentation, is important for broadening their accessibility and facilitating their application in practice.

Computational efficiency. The detailed simulations that AABMs perform, especially at large scales, require considerable computational power. This is especially true for the simulation of traffic flows. Achieving computational efficiency while maintaining model accuracy and fidelity is a major issue. Techniques such as model optimisation, the use of high-performance computing platforms and the development of algorithms for parallel processing are important to meet the requirements.

Integration challenges. Integrating AABMs with other planning tools and data systems can be complex, given the diversity of data formats and the complexity of model interfaces. Overcoming these integration challenges requires standardisation efforts and the development of solutions that facilitate data exchange and interoperability between different modelling systems and planning tools.

Concluding, the comparison of AABMs with traditional models shows that AABMs are better able to simulate complex human behaviours and their interactions within transport systems. The integration of demand generation with traffic flow simulation is a key advantage and provides comprehensive insights into the effects of policy interventions. However, overcoming usability and computational efficiency issues are essential to maximise the potential of AABMs in large-scale applications and ensure their practical utility in transport planning and policy development.

4.3.4 Modelling public transport and mobility

The discussions on modelling public transport and mobility focused on the task of incorporating public transport data and considering mobility options within activity-based models, such as cycling or multi-modal transport. This integration is important for accurately simulating the full spectrum of mobility (urban, regional, national, international), reflecting the varied travel behaviour and preferences that characterise the contemporary mobility landscape. The integration of detailed transport data, as illustrated by the General Transit Feed Specification (GTFS), and the consideration of cycling as an important form of transport, are important for constructing realistic models (not only AcBMs, but also the traditional models!). These elements underscore once more the complexity and multidimensionality of transport systems and challenge modellers to reproduce the nuances of real-world travel dynamics.

Inclusion of public transport data

Integration of GTFS. The application of GTFS, a common format for public transport schedules and associated geographical information, improves the capacity of models (both traditional and AcBMs) to accurately simulate public transport use. This integration enables detailed representation of routes, schedules and stops, allowing the models to reflect the true availability and accessibility of public transport services. However, integrating GTFS data into AcBMs requires considerable effort, as transit schedules need to be aligned with the simulated daily activities and travel patterns of individuals, unlike traditional models that usually model daily periods at an aggregated level such as morning peak or evening peak.

Challenges and solutions. One of the main points in integrating GTFS data is ensuring that the model can adapt to the temporal and spatial variability of transit services. Solutions include developing algorithms that can interpret GTFS data so that simulated individuals can make public transport choices that reflect actual service conditions. In addition, calibrating models to account for factors such as capacity constraints, service interruptions and seasonal variations in service levels is important for improving the realism of simulations.

Modelling cycling and multimodal transport

Cycling as a mode of transport. Recognising cycling as a vital component of urban and regional mobility is essential for comprehensive mobility modelling. This requires the inclusion of detailed data on cycling infrastructure, such as bike lanes and parking facilities, as well as considerations of topography and connectivity. Accurate modelling of cycling also involves understanding the factors that influence individuals' decisions to cycle, including distance, convenience, and cultural attitudes towards cycling.

Multimodal transport dynamics. Modelling multimodal transport involves additional layers of complexity as it involves simulating the decision-making processes behind the use of multiple transport modes within a single journey. This requires a nuanced understanding of how individuals evaluate trade-offs between different transport modes, such as convenience, cost, travel time and environmental impact. Effective multimodal transport modelling (not only for AcBMs, but also traditional models) requires the integration of different data sources and the ability to simulate seamless transitions between modes, including the intermodal connections between cycling, public transport, and other forms of mobility.

Need for good transport networks. Accurate modelling of public transport and multimodal transport highlights the need for detailed representations of transport networks. This includes not only the physical infrastructure, but also the operational characteristics and services of different public transport modes. Achieving this level of detail is essential for simulating the diverse mobility patterns observed in urban areas, from daily commuting to leisure trips. The challenge lies in collecting and maintaining up-to-date data on all modes of transport and ensuring that the model's network representations are both accurate and flexible enough to accommodate changes in the mobility landscape.

Conclusion

The discussions on public transport, cycling and mobility models highlight the importance of integrating detailed transport data and considering a wide range of mobility options within activity-based models, although this also holds for the traditional models. It is important to improve the reliability and applicability of transport models so that they can serve as effective tools for spatial planning, policy development and the promotion of sustainable mobility solutions.

4.4 Data issues

4.4.1 Data requirements and technical considerations

The interviews addressed the role of detailed data in the development and implementation of AABMs, the importance of big data, the need for privacy considerations, and the dynamic nature of data sources used for model development. These aspects are important to the effectiveness and reliability of AABMs and affect their ability to simulate complex human behaviours and interactions within the transport system.

The need for detailed data. The basis of AABMs lies in their ability to simulate the travel behaviour of individuals and households with a high degree of granularity. This requires the collection and integration of detailed data, including socio-demographic characteristics, travel and activity diaries, location preferences and other behavioural indicators. Such data enable the models to capture the diversity of human activities and their corresponding travel patterns, facilitating a nuanced understanding of transport dynamics. However, obtaining the data has its issues, including the need for extensive surveys, integration of disparate data sources and continuous updating of datasets to reflect changing behaviour.

Challenges in data processing. Processing data for AABMs involves processes of data cleaning, data integration, and data analysis. One of the main problems is ensuring data representativeness and accuracy, which is important for the validity of model outputs. The data processing must address issues of data sparsity, biases, and inconsistencies, which require advanced statistical and computational techniques. Moreover, the dynamic nature of human behaviour and urban areas requires adaptive data processing methods that can adapt to changing patterns and trends.

The role of big data. The advent of big data technologies has changed the landscape of data sources for AABMs and offers opportunities to improve model development. Data from sources such as mobile phone data, GPS devices, social media platforms, and sensor networks offer rich insights into human mobility patterns and urban dynamics. These data sources complement traditional data sources, allowing models to be calibrated more accurately and quickly. However, the use of big data also brings complexities related to data processing, analysis, and integration of heterogeneous datasets.

Privacy considerations. The use of detailed data and big data in AABMs raises privacy concerns, requiring strict data protection measures. Ensuring the anonymity and confidentiality of individual data is paramount, requiring anonymisation techniques and secure data handling practices. Moreover, the use of personal data should be guided by legal frameworks and ethical guidelines, balancing the benefits of model development with the need to protect individuals' privacy.

Evolving landscape of data sources. Data sources for AABMs are constantly evolving, driven by technological advances and changes in data generation and collection. This dynamic landscape presents both opportunities and challenges for model developers. On the one hand, it provides opportunities for more comprehensive and up-to-date datasets; on the other, it requires continuous adaptation of data collection, summarisation, and analysis methods to effectively exploit these new sources.

Concluding, the interviews have highlighted the complexity and importance of data management in the development and deployment of AABMs. Addressing the challenges associated with processing data, harnessing the potential of big data, dealing with privacy issues, and adapting to the changing landscape of data sources are important to the success and reliability of these models. These considerations are integral to the ongoing development of AABMs and ensure that they provide insightful and useful results for transport planning and policy analysis.

4.4.2 Integrating big data and advanced analytics

The use of big data represents a paradigm shift towards the use of large and complex datasets, alongside advanced analytical methods, to improve the calibration, validation, and improvement of model results. This shift is characterised by the integration of big data - a wide range of information from GPS tracks, mobile phone data, social media activity, and sensor networks - into the modelling frameworks. At the same time, machine learning algorithms and advanced analytics are increasingly being used to detect patterns, predict behaviour, and refine the creation of synthetic populations that accurately reflect real-world demographics and travel behaviour. This integration marks a new step in transport modelling, characterised by improved precision and policy relevance.

Opportunities through big data and advanced analytics

Improved model calibration and validation. Input from big data enables more fine-grained and accurate calibration of transport models, so that simulated behaviour closely matches observed reality. Advanced data analytics, particularly machine learning techniques, can automate the identification of behavioural patterns, thus facilitating refined model validation processes.

Refinement of synthetic populations. By using different data sources, modellers can generate more representative synthetic populations. These populations are essential for simulating the range of activities, travel patterns and decision-making processes within a given area, improving the predictive accuracy of models.

Real-time data use. The real-time nature of many big data sources allows models to reflect current trends and emerging patterns, allowing transport systems to be dynamically assessed and policy interventions to be directly evaluated.

Challenges in integrating big data and advanced data analytics

Data quality and representativeness. Despite the abundance of data, challenges remain regarding its quality, completeness, and representativeness. To avoid biases in model outcomes, it is important to ensure that big data sources accurately reflect the demographics and behaviour of the entire population.

Privacy considerations. The use of detailed individual-level data raises privacy concerns. Protecting the anonymity of individuals while using their data for modelling purposes requires strict data management protocols and ethical considerations.

Integration of new data sources. Integrating heterogeneous big data sources into existing modelling frameworks poses technical issues. This requires developing data processing procedures and adapting models to handle new data types, all while maintaining computational efficiency and model integrity.

4.4.3 Importance of high-quality data

Fundamentals of data quality. The effectiveness of all models (and thus AcBMs) is dependent on the quality of the underlying data, including detailed information on individual and household activities, travel and activity diaries and sociodemographic characteristics. High-quality data not only improve the behavioural realism of the model, but also support calibration and validation processes.

Continuous data improvement. As different organisations move to AcBMs, a continuous commitment to improving data collection and processing methods is essential. This includes using new data collection technologies, such as mobile GPS tracking or social media analytics, and refining data processing techniques to improve accuracy and representativeness.

4.5 Process and organisation

4.5.1 Transition to activity-based models

Different interviews touched upon the topic of transition to activity-based models. This concerns the considerations and methodological advice for entities transitioning from traditional travel or tour models to the more nuanced and complex activity-based models (AcBMs). This transition is essential for reproducing a more detailed and behaviourally accurate representation of travel demand, reflecting the shift towards understanding transport as an integral part of daily activities and lifestyle choices. Advice on this transition emphasises a gradual, step-by-step approach, highlighting the critical importance of baseline data quality, model validation and the step-by-step integration of complex elements.

Gradual approach to transition

Starting with simpler models. The consensus among experts is that the transition to AcBMs should start with simpler, more basic AcBMs that capture the essential dynamics of travel behaviour without overwhelming modellers and policy makers with complexity. This first step allows entities to adapt to the conceptual framework of activity-based modelling, including the representation of individual and household activities and their implications for travel.

Stepwise integration of complexity. After establishing an activity-based basic framework, the gradual integration of more complex elements is recommended. This may include the gradual addition of detailed activity types, finer spatial resolutions, or more sophisticated decision-making algorithms. Such an incremental approach ensures that modellers can systematically assess the impact of each new element on model performance and accuracy, enabling a controlled evolution towards full-fledged AcBMs.

Careful validation

Iterative validation process. Validation should be seen as an iterative process, guiding each stage of model development. As new elements are integrated into the AcBM, validation efforts can help identify and correct potential discrepancies or biases, keeping the model in line with empirical observations.

4.5.2 Model size and scalability

Model size and scalability focuses on the aspects of designing and scaling activity-based models (AcBMs) to accommodate different geographical and population scales. AcBMs are often applied to regions with populations of one to three million people. This scale was chosen to strike a balance between the richness of behavioural detail and the computational feasibility of the models. However, the ambition to apply AcBMs at a larger scale, such as at the national level, poses challenges related to network complexity and data management.

Challenges of scaling models to national level

Network complexity. As the scale of the model increases to comprise larger geographical areas and larger populations, the complexity of the transport network and the diversity of travel behaviour increases as well. This complexity is a point of attention for model calibration and validation and for representing the dynamics of interregional travel. The detailed nature of AcBMs, including the simulation of individual travel patterns and choices, is becoming increasingly difficult to manage on a national scale due to the huge increase in the number of agents and interactions to be simulated.

Data management and computing power. Scaling AcBMs to larger regions requires handling larger datasets, including demographic information, travel and activity diaries, and detailed representations of the transport network. Managing such datasets requires significant computing resources, both in terms of computing power and memory. Moreover, the computational time required to simulate larger models can become prohibitive, making the use of AcBMs for large-scale applications impractical.

Strategies for managing model size and scalability

Development of detailed local sub-models. Another approach is to develop detailed local sub-models that are integrated into the broader national modelling framework. These sub-models can focus on specific urban areas or regions with high population density and complex transport networks, allowing for detailed behavioural simulations in these areas. The sub-models can then be linked to the larger model through simplified representations of travel behaviour and patterns outside the detailed areas. This hierarchical modelling approach enables the nuanced simulation of travel behaviour in key areas, while maintaining the feasibility of simulations at the national level.

Hybrid modelling approaches. Hybrid approaches that combine the strengths of AcBMs with more aggregated modelling techniques can also facilitate the scale-up of models to larger areas. For example, aggregated models can be used to simulate long-distance and interregional travel, while AcBMs are applied to reproduce detailed travel behaviour within specific regions. This combination enables efficient handling of different mobility scales and can improve model scalability without compromising the depth of behavioural insights.

4.5.3 International cooperation and knowledge sharing

The interviews highlight the benefits that can be realised through cross-border partnerships and the open exchange of models, data, and expertise. In an era where transport and mobility trends increasingly transcend national borders, fostering international cooperation is an important strategy to improve the accuracy, relevance, and applicability of transport models. This joint approach not only facilitates the pooling of resources and knowledge, but also promotes the application of best practices in different regions, contributing to the advancement of the field and the development of more sustainable and efficient transport systems worldwide.

Benefits of international cooperation

Improved accuracy of models. Collaboration between countries and regions enables the sharing of different datasets, including travel surveys, land use patterns and infrastructure data, enriching the data sources available for model calibration and validation. Access to a wider range of data improves model accuracy by enabling more comprehensive and diverse representations of travel behaviour and mobility patterns. This is especially beneficial for regions with limited data collection capabilities, as it allows them to leverage insights from environments with more data.

Introduction of best practices. International cooperation provides a platform for the exchange of methodologies, techniques, and experiences in transport modelling. This exchange promotes the identification and adoption of best practices, including innovative approaches to model development, calibration, validation, and deployment. By learning from the successes and problems in different contexts, the governmental entities of SIVMO can refine their modelling practices by adopting strategies that have proven effective elsewhere.

Addressing common challenges. Many transport challenges, such as congestion, emissions, and the integration of new mobility services, occur in different regions. International cooperation makes it possible to jointly explore solutions to these challenges and facilitate the development of models that can simulate the impact of different policy interventions and infrastructure investments on a global scale. Collaborative research projects and initiatives can focus on specific problems, pooling expertise, and resources to achieve more effective results.

Strategies to facilitate collaboration and knowledge exchange

Establish international knowledge networks. Establishing formal networks and consortia for transport modelling facilitates structured collaboration and knowledge sharing. These networks can organise conferences, workshops and webinars that bring together modellers, policymakers, and practitioners from around the world, fostering a sense of community and ongoing dialogue.

Open access to models and data. Promoting open access policies for transport models and datasets improves international cooperation. By making models and data publicly available, regions can contribute to a shared repository of resources that can be used and built upon by modellers worldwide. This approach requires attention to data privacy and intellectual property but offers significant benefits for model development and application.

Joint research and development projects. Engaging in joint research and development projects is another effective strategy for international cooperation. These projects can be supported by partnerships between government, academia and the private sector and focus on common goals such as improving modelling techniques, investigating emerging trends in transport, and assessing policy interventions in different contexts.

4.5.4 Conclusions

The transition to activity-based models represents an important step forward in transport planning and offers deeper insights into the complex interplay between human activity and travel behaviour. The advice to adopt a gradual, methodically structured approach to this transition underscores the need to balance complexity and manageability by ensuring that the development of AcBMs is both well-considered and data driven. By prioritising high-quality data and validation, entities can steer the complexity of this transition and harness the full analytical power and policy relevance of activity-based modelling.

The discussions on model size and scalability highlight the challenges and considerations involved in applying activity-based modelling approaches to larger geographical scales and populations. Addressing these issues requires innovative approaches to model design and implementation, including the development of detailed local sub-models, or the application of hybrid modelling techniques. These strategies aim to preserve the behavioural richness and analytical depth of AcBMs while making them more scalable and applicable in a wider range of planning and policy analysis contexts. As computing capabilities continue to increase and new methodological approaches are developed, the scalability of AcBMs is likely to improve, increasing their applicability and usefulness in addressing complex transport planning questions.

International cooperation and knowledge sharing in transport modelling provide a path to more accurate, innovative, and universally applicable models. By fostering cross-border collaborations and the open exchange of data, models and expertise, the transport modelling community can address common challenges, adopt best practices, and contribute to the development of sustainable and efficient transport systems worldwide. This collaboration not only improves the technical aspects of modelling, but also strengthens the global commitment to improving mobility and quality of life through informed planning and policymaking.

4.6 Policy

4.6.1 Policy implications and applications

AABMs play a facilitating role in policy analysis for transport, spatial planning, and infrastructure development. The models provide a nuanced simulation of individual and household activities and travel behaviour, providing policymakers and planners with a robust framework for evaluating the potential impacts of various policy interventions. The depth of analysis offered by AABMs is particularly valuable for discerning the responses of individuals and communities to changes in the transport system, urban areas, and policy measures. AABMs provides the framework to link people data, transport/network data, land-use data and environmental data in consistent way. This is considered essential in addressing the environmental challenge, equity analysis, and land-use development.

Facilitating policy analysis. AABMs are equipped to address a broad spectrum of policy questions, as they can encompass the complex interactions between individual behaviour, household dynamics, and transport infrastructures. Among other things, they can simulate the effects of policy measures on travel demand, mode choice, traffic congestion, environmental impacts, and social equity, among others. This enables policymakers to weigh the potential benefits and trade-offs of different policy alternatives, to support well-informed decision-making processes.

4.6.2 Examples of policy questions addressed by AABMs

- *Impacts of transport pricing policies*. AABMs can investigate more detailed (by means of looking at the duration for example) how strategies such as congestion charges, parking tariffs, or changes in public transport fares affect behaviour. By simulating individual decision-making processes, these models can predict shifts in mode choice, changes in vehicle kilometres travelled, and changes in transport composition, shedding light on the efficiency of pricing strategies in managing congestion and promoting sustainable transport modes.
- *Evaluation of infrastructure investments*. Like traditional models, AABMs can assess the expected impacts of new transport infrastructure, such as the construction of bicycle lanes, the expansion of the public transport network, or the creation of pedestrian-oriented urban areas. The models can predict changes in accessibility, the redistribution of traffic flows, and land-use implications, helping to align infrastructure investments with broader urban development goals. The difference between AABMs and traditional models is that they also can relate the impacts in more detail to different user groups.
- *Land use policy analysis*. By integrating land use and transport modelling, AABMs can examine the outcomes of land use plans, densification initiatives, and policies to promote mixed-use developments. These models reveal the interrelationships between land-use decisions, travel behaviour, and urban morphology.
- *Assessment of technological innovations*. AABMs can examine the potential impacts of emerging transport technologies, such as autonomous vehicles or mobility-as-a-service platforms. By simulating the influences of these innovations on travel choices, vehicle ownership patterns, and overall system efficiency, policymakers can identify the points of attention and opportunities presented by technological developments.
- *Exploration of social equity considerations*. AABMs make it possible to explore how transport policies affect different population groups, including poor households, the elderly, or communities with limited access to transport alternatives. These models can reveal inequalities in access to employment, education, and essential services, so that policies can be developed that promote equity and inclusiveness.
- *Assessing environmental outcomes*. Transport models in general (and thus AABMs) are important in conducting environmental impact assessments, allowing policymakers to quantify the potential impacts of transport projects and policies on air quality, greenhouse gas emissions and energy consumption. By simulating changes in travel behaviour, vehicle use and modal split in response to policy interventions, models can predict environmental outcomes, facilitating the identification of strategies that contribute to environmental sustainability.
- *Informing long-term planning.* The development of regional mobility plans depends on the insights provided by transport models. These models help understand current mobility patterns, identify future transport needs, and assess the impact of demographic changes on travel demand. This capability supports strategic planning of infrastructure investments and the design of mobility services aligned with long-term regional development goals.
- *Accommodating new mobility trends*. As mobility evolves with new trends such as shared mobility services, autonomous vehicles and micro-mobility solutions, models are essential for understanding and planning for these changes. They provide insights into how these innovations may change travel behaviour, demand for different modes of transport and interaction with existing transport infrastructure. This informs the development of policies and infrastructure

adaptations that integrate new mobility options to complement and improve the overall transport system.

- *Contribution to spatial planning and infrastructure development.* Within the context of spatial planning and infrastructure development, AABMs serve as a tool for understanding how changes in the built environment affect travel behaviour and community well-being. By simulating the daily activities of individuals and the resulting travel patterns, these models provide insights into the strategic placement of transport facilities, and the integration of sustainable mobility solutions. The detailed scenario analyses enabled by AABMs help formulate policies that improve liveability, promote efficient land use, and support the transition to more sustainable and resilient environments.
- *Scenario analysis*. Models make it possible to examine different scenarios, such as the implementation of congestion charging or improvements to public transport systems. Scenario analysis allows comparing the environmental benefits of different policy options, allowing decisions to be made that maximise environmental benefits. It allows us to simulate different population groups in any geographical area of interest with special features to understand their transport needs and the impacts of new transport initiative on each group. The AABM thorough scenario analysis also provides the means to quantify uncertainties in our model assumptions and external factors.

4.6.3 Conclusion

For policy analysis and infrastructure planning, transport models in general provide insights that support decision-making. By simulating the dynamics of travel behaviour and its interaction with transport networks, these models support the evaluation of environmental impacts, the formulation of regional mobility plans and the strategic development of infrastructure to meet emerging trends. AABMs are better equipped to underpin detailed travel behaviour then the traditional transport models. The potential of models to guide policy decisions and infrastructure investment highlights their role in shaping sustainable, efficient, and adaptable transport systems for the future.

4.7 Future developments

4.7.1 Future directions on methods

The discussions on future directions and developments in transport modelling includes insights into the trajectory of progress in the field, focusing on the integration of activity-based and agent-based approaches, innovations in modelling techniques and the critical balance between model complexity and policy needs. This perspective highlights possible paths for improving the effectiveness, relevance, and applicability of transport models in addressing the questions of mobility and policy formulation.

Improved integration of activity-based and agent-based approaches. For the longer term, the future of transport modelling is likely to be characterised by a more seamless integration of AABMs, leveraging the strengths of both approaches to produce richer, more dynamic simulations of travel behaviour and system performance. This integration promises to provide a holistic view of transport systems, directly linking the micro-level decisions of individuals and households to macro-level phenomena such as network congestion, environmental impacts, and urban sprawl. Advances in computing techniques and data analysis are expected to facilitate this integration, enabling the simulation of complex interactions within and between transport ecosystem components.

Advancements in modelling techniques. Innovations in modelling techniques, driven by big data, machine learning and artificial intelligence, are expected to improve the predictive accuracy and operational efficiency of transport models. Machine learning algorithms, for instance, can improve model calibration by identifying patterns and relationships in large data sets that are not apparent through traditional analysis. Similarly, artificial intelligence can help decision-making processes in models, by simulating the behaviour of travellers in response to changes in the transport environment. These developments promise to expand the capabilities of transport models to respond to the changing dynamics of mobility.

Aligning model complexity with policy needs. A critical consideration for the future development of transport models is matching model complexity to the specific needs of policy analysis and decision-making. While the detailed simulation capabilities of AABMs offer in-depth insights into the dynamics of transport, it is increasingly recognised that models need to be both accessible and manageable for policymakers and practitioners. This requires a thoughtful balance, where models should be sufficiently detailed to capture the essential dynamics of transport systems, yet also sufficiently streamlined to be practical for policy evaluation and scenario analysis. Strategies to achieve this balance include modular model designs, the development of user-friendly interfaces and the integration of flexible model frameworks that can be adapted to different policy contexts.

4.7.2 Future of ICT

Advances in computing technologies. Future directions in transport modelling also include the use of advanced computing technologies, such as cloud computing platforms. These technologies are expected to address current limitations in computational requirements and enable the execution of more complex models over larger geographical areas and longer time horizons. The scalability and efficiency of transport models is likely to improve significantly, enabling more comprehensive and detailed analyses of transport systems. The advancements in computing technologies also expands the possibilities for managing stochasticity and complexity in transport models.

Enable real-time modelling and forecasting. Upgrades in ICT network technologies are expected to enable the development of real-time transport models that can predict short-term changes in travel demand and system performance. This capability would be instrumental in supporting dynamic traffic management and real-time interventions, contributing to more responsive and adaptive transport systems.

Integration of artificial intelligence and machine learning. The interviews highlight the growing integration of artificial intelligence and machine learning algorithms into the practice of transport modelling. These technologies provide tools for processing large data sets, identifying complex patterns and predicting future trends based on historical data. Artificial intelligence and machine learning can enhance the ability of models to simulate adaptive and responsive travel behaviour, considering the impact of policy changes, infrastructure developments and emerging mobility services.

4.7.3 The future of data

Big data and advanced analytics. The integration of big data and advanced analytics into transport modelling is promising for the advancement of the field, offering the potential for models that are more responsive, accurate and reflect complex human behaviour. However, to realise this potential, challenges must be overcome, especially in the areas of data management, privacy protection and the technical integration of various data sources. As the field develops, fostering collaboration between data owners, data scientists, modellers, policymakers, and privacy experts will be essential to reach the benefits of big data and advanced analytics while addressing the associated risks.

4.7.4 Conclusion

The insights from the interviews underline the consensus among international experts on the potential of technological developments in transport modelling. The anticipation of future developments, including improved data collection methods, the integration of AI and ML, and advances in computing technologies, point to a future in which transport models may become more accurate, dynamic, and better able to inform policy and planning decisions. The potential impacts of network upgrades further highlight the potential for improved collaboration, model accessibility and the advent of real-time modelling capabilities, representing a significant leap forward in the pursuit of sustainable and efficient transport systems.

4.8 Advantages and disadvantages of AABMs

4.8.1 Main advantages and disadvantages of AABMs

The discussions on the pros and cons of AABMs provide a good insight into the strengths and limitations of these modelling approaches in transport planning and policy analysis. AABMs offer important insights into the patterns of daily activities and travel behaviour of individuals and households and provide a detailed picture of transport dynamics. However, the adaptation of these models has its issues, mainly due to their complexity, the extensive data requirements, and the considerable computing power needed.

Advantages of AABMs

- *Detailed simulation of daily patterns and household dynamics.* One of the key strengths of AABMs is their ability to simulate the detailed daily activity patterns and travel behaviours of individuals and households. By focusing on the activities that determine transport demand, these models provide a richer, more nuanced understanding of travel behaviour, capturing the sequence of activities, the interaction between household members' schedules, and the influence of social and economic factors on travel choices.
- *Improved sensitivity to policy*. AABMs are better capable to provide insights in a wide range of policy interventions. It makes them more valuable for evaluating the effects of transport policies, spatial planning strategies, and infrastructure investments. The representation of more detailed individual and household behaviour makes it possible to assess how specific policies might influence travel patterns and mode choice, by relating them to different user groups.

- *Flexibility and adaptability*. The agent-based component of AABMs offers a high degree of flexibility, allowing different behavioural theories to be integrated and complex interactions within the transport system to be simulated. This adaptability makes AABMs suitable for exploring different policies and the potential impacts of innovative transport solutions, such as autonomous vehicles and shared mobility services.

Disadvantages of AABMs

- *Model complexity*. The detailed nature of AABMs results in considerable model complexity, which can pose challenges in terms of knowledge management, model development, calibration, and validation. The complexity requires in-depth knowledge of both the theoretical underpinnings of the models and the technical skills required for their implementation, which can limit their accessibility to a wider range of practitioners and policymakers.
- *Extensive data requirements.* AABMs rely on detailed data on individual and household activities, preferences, and socio-demographic characteristics. Collecting and processing these data can be resource-intensive, as a considerable effort is required to collect, process, and maintain data. Moreover, the availability of such detailed data may be limited, especially in regions with limited data collection resources.
- *Computational requirements.* The simulation of detailed activity patterns and agent interactions within AABMs requires considerable computational power, especially for large-scale applications. The computational intensity can lead to long run times and may require the use of high-performance computing facilities, which can be a barrier for institutions with limited technical infrastructure.
- *Privacy concerns.* The detailed data required for AABMs may raise privacy concerns, as it often contains sensitive information about individuals' locations, activities, and preferences. Ensuring data privacy and security is a critical issue that requires strict data protection measures and ethical considerations when handling personal information.

While AABMs offer significant advantages in terms of the depth and richness of insights they provide into the dynamics of transport, their implementation is challenged by issues related to model complexity, data requirements, computational demands, and privacy. Balancing the strengths and limitations of AABMs is essential for exploiting their potential to effectively inform transport planners and policy decision-making. The following sections discuss this further.

4.9 Examples

Worldwide there are different examples or best practices of AABMs. Below a few examples of activity- and agent-based models or components that serve an AABM. It is by no means complete, but it shows that these models are used widely.

- *AB-Motion*. AB Motion is an AcBM used by Transport for London (TfL). This model aims to provide insights in travel patterns and behaviours in London. By integrating different data sources, including Oyster card data, AB Motion simulates the daily activities and travel decisions of London residents. The model provides insights into the impacts of different transport policies, infrastructure changes, and emerging mobility trends such as cycling and ride-sharing services.

- *COMPASS*. In Denmark, the city of Copenhagen has developed COMPASS (an AcBM) to address urban mobility challenges. The model incorporates data from various sources, including travel surveys and real-time data from public transport systems. COMPASS simulates individual travel behaviours and interactions, to explore scenarios related to congestion management, public transport improvements, and the introduction of new mobility services.
- *PopSim*. Another example is PopSim, used in several transport models, including those in Switzerland by SBB (Swiss Federal Railways). PopSim is a population synthesis tool that generates a detailed synthetic population based on demographic and socio-economic data. This technique is important for developing an AABM, as it provides data required for simulating travel behaviours. PopSim has been integrated into larger transport models to analyse travel demand and optimise public transport services.
- *MATSim.* MATSim (Multi-Agent Transport Simulation) is widely used in various countries, including Switzerland and Germany. MATSim is an open-source platform that provides a framework for developing agent-based transport simulations. It allows for the simulation of individual travel behaviour over a typical day, considering various activities and interactions within the transport network. The flexibility and scalability of MATSim make it a good tool for analysing the effects of different transport policies, infrastructure developments, and mobility services.
- *ActivitySim*. ActivitySim is utilised primarily in the United States. This open-source software package is designed to simulate individual travel behaviour based on daily activity patterns. ActivitySim uses demographic data and travel surveys to model the decisions and interactions of individuals and households. Its framework allows for customisation and integration with other transport models, providing a solution for regional and urban planning agencies.
- *ALBATROSS.* This is an AcBM developed in the Netherlands. This model focuses on predicting the activity-travel patterns of individuals and households based on a comprehensive set of rules derived from observed behaviour. ALBATROSS incorporates various factors, including socio-demographic characteristics, land use, and temporal constraints, to simulate daily activity schedules and corresponding travel decisions.
- *Feathers.* Feathers is a AcBM framework, which integrates detailed individual and household data to simulate daily activity patterns and travel behaviours. This framework allows for the assessment of policy impacts on travel demand, land use, and environmental outcomes. By capturing the interactions between personal activities and transport choices, Feathers provides insights into the effects of various transport policies and infrastructure developments.
- *Flanders model*. The model for Flanders, Belgium, is an AcBM to address regional transport planning and policy analysis. The model integrates demographic, land use, and transport network data to simulate the travel behaviour of individuals and households across Flanders. It is used to explore the impacts of various policy measures, including congestion pricing, public transport improvements, and infrastructure developments.

Annex 5 Interview notes

5.1 Introduction

Interviews were conducted with various experts, including academic experts, government officials and consultants to address the different topics on AABMs. Although the key questions asked in these interviews were related, distinctions were made to accommodate the specific expertise of each respondent. In addition, the arrangement of interviews in this appendix is chronological, based on the date each interview was conducted. This sequencing is deliberate, as certain interviews contain references to previous discussions, which improves the overall comprehensibility of the data collected.

We held in-depth interviews with several experts/organisations at home and abroad of one hour on the questions at hand. In the period September-December 2023, we conducted 22 interviews with 24 persons. These interviews took place through Teams to save time and costs.

The format of the interviews was as follows: in one hour (with a possible run-out of half an hour) the questions were discussed. The emphasis varied from interview to interview, depending on the interviewee. With governments, for example, the emphasis was more on applications, while with knowledge institutions the emphasis was more on method and development.

We selected the interviewees in consultation with the client. We preferably approached the interviewees personally. We prepared questions and sent them in advance so that the interviewees could prepare themselves. Each interview was recorded for taking notes. The notes were first shared with the interviewee for approval. The interviews were conducted by the contractor and SIVMO. To enhance the international nature of the work, we sought interviewees in Europe and US.

Several research questions were addressed during the interviews. Together with the client, we drew up a final questionnaire. Some examples of questions:

- What is the difference between activity-based and agent-based models. How do you define both types of models?
- What are the advantages and disadvantages of these models?
- What is the status of these models?
- What are the biggest challenges to implementing activity-based or agent-based models?
- What are the total costs and time for developing activity-based or agent-based models?
- What policy questions can activity- and/or agent-based models (better) answer? What do you deploy them for?
- Content questions on delineation of study area, population synthesis, stochasticity, etc.

The format of the interviews via Teams was as follows:

- Inviting the interviewee (preferably through personal channels)
- Include questions in the invitation so that people already can think about answers
- Drawing up the questionnaire (with general and specific questions)
- Interview via Teams with the interviewee
- Running down the questions
- Drafting a report and send it to interviewee for comments
- Finalise notes and include it in the report.

Interviews were conducted with the following persons (in alphabetical order with abbreviations):

- Kay **Axhausen** – KWA (page 148);
- Alex **Bettinardi** – AB (page 212);
- Pascal **Boonstra** and Michiel **van Bokhorst** – PB & MB (page 195);
- Luuk **Brederode** – LB (page 139);
- Mark **Bradley** – MB (page 170);
- Cinzia **Cirillo** – CC (page 180);
- Andrew **Daly** – AD (page 127);
- Leonid **Engelson** – LE (page 144);
- Tim **Heirman** – TH (page 165);
- Soora **Rasouli** – SR (page 206);
- Charlene **Rohr** – CR (page 190);
- Erik de **Romph** – ER (page 174);
- Nila **Sari** – NS (page 217);
- Wolfgang **Scherr** – WS (page 136);
- Maaike **Snelder** – MS (page 199);
- Ben **Stabler** – BS (page 184);
- Collins **Teye** and Tim **Price** – CT & TP (page 155);
- Filip **Vang** – FV (page 159);
- Kurt **Verlinden** – KV (page 132);
- Peter **Vovsha** – PV (page 152);
- Tom **van Vuren** – TV (page 123);
- Luis **Willumsen** – PW (page 119).

In the interview notes, abbreviations are used for the names of individuals (as detailed in the preceding list). Additional abbreviations concern the interviewers:

- Jan **Kiel** – JK
- Marits **Pieters** – MP
- Amand **Stevens** – AS
- Anne **Jousma** – AJ
- Servé **Hermens** - SH
- Mirco **Hogetoorn** - MH
- Lucia **Schlemmer** - LS

5.2 Luis Willumsen

Luis (Pilo) Willumsen is an independent consultant and a managing partner at Nommon Solutions and Technology.

Context and definitions

According to PW, agent-based modelling involves micro simulation models where agents, representing individuals making choices and entities like vehicles and taxis are managed and interact with individual agents. Activity-based modelling focuses on activities such as the underlying reason behind the travel purpose, identifying important activities, their allocation in space and time, and their linkage through trips and tours efficiently. In today's practice, activity-based models are mostly implemented as agent-based models. PW emphasises that often the definition of "activity-based models" varies widely and often encompasses tour-based models rather than true activity-based models.

PW emphasises that to adequately consider the various new modes of transportation (such as taxis, e-scooters, bicycles, autonomous vehicles), especially demand-responsive modes such as car-sharing, agent-based models are likely to be needed. Their complexity necessitates agent-based models to handle these modes effectively and developing appropriate supply models. PW also notes the challenges in dealing with empty vehicles (like empty taxis) and highlights the limitations of static assignments in addressing these issues, suggesting the need for micro simulation assignments.

The discussion moves to the assignment step in modelling and the need to consider active modes. PW suggests that we need to consider what the specific problem being addressed is. For a city like Barcelona, aiming for a 15-minute city concept, walking and cycling are important, but it might not be significant when considering city-wide congestion, for example. Overall, PW emphasises the need to tailor the choice of modelling approach based on the specific problems to be addressed, the types of transportation modes involved, and the available data, advocating for a problem-oriented and flexible modelling strategy.

Data

PW emphasises the difficulty in obtaining detailed data on activities, especially in terms of the negotiations within households to reorganise them. There's a lack of comprehensive survey instruments to collect necessary data, and the future changes in activities further complicate modelling efforts. The interviewee questions the level of aggregation for making forecasts about future activities and the need to explore different scenarios and strategies rather than relying solely on data.

The discussion discusses the use of passively collected data, such as phone or smartcard data, as a potential source. However, PW notes that this data is simple, and it lacks information on individual travellers and their intentions. Very simple agent based models could be developed but they have limitations (A Bassolas, JJ Ramasco, R Herranz, OG Cantú-Ros (2019) Mobile phone records to feed activity-based travel demand models: MATSim for studying a cordon toll policy in Barcelona - Transportation Research Part A: Policy and Practice.).

JK mentions the long-standing household surveys in the Netherlands, which provide data on households, individuals, and trips on a continuous basis for 45 years. However, PW raises concerns about the depth of this data, especially its focus on one-day averages. He argues that to truly capture activities and their rescheduling, a deeper understanding, possibly on a weekly basis, is necessary. The conversation challenges the approach of current models, which often rely on one-day averages, questioning the need to delve deeper into activity schedules and the importance of understanding the underlying decisions.

PW emphasises the importance of identifying specific problems that need solving when considering the level of detail in the data. He suggests that it is always possible to seek even deeper understanding, beyond activities, for the reasons for travel: understanding values and lifestyle changes, such as shifts in religious practices, can be seen as essential in modelling human behaviour accurately. However, it may be impossible (and even unethical) to pursue this level of understanding of human behaviour. When developing transport models, we should seek to identify the level of granularity required to address a problem and at the same time be confident that at that level we can have the data necessary to feed the model.

Overall, the interview underscores the complexity of obtaining detailed activity data, challenges in forecasting future activities (we have changed our preferred activities in the past; we may change them again in the future inb ways we cannot predict; AI and virtual reality impacts?). There is a need for a nuanced approach that aligns the level of data detail with the specific problems being addressed in AABMs.

Methods

The discussion focuses on the technical aspects of AABMs, including geographic scope, handling uncertainties, model validation, and the advantages and limitations of these models.

PW explains that AABMs are primarily designed to model residents/individual agents, not freight (typically, although this is changing with the rising complexity of logistics in urban areas and deliveries). Freight typically has been modelled in an aggregate manner, with through-traffic treated in a traditional, pre-loaded way onto the network, as it's not feasible to combine static and micro-simulation assignments simultaneously. External trips are also often treated in an aggregate manner.

JK questions the role of stochasticity in AABMs and its importance. PW suggests that models should be designed to be reproducible. Multiple runs with different random numbers should be performed to obtain an average, which provides more stable results. Convergence of the system can be achieved by repeating runs. PW also discusses the legal perspective and the importance of reproducibility for model results.

The discussion then touches on the use of pivot-point models and the challenge of consistency between activity-based models and pivot-point methods. PW notes that activity-based models may not be suitable for pivot-point modelling due to their detailed nature.

AS discusses the use of base models for studies and whether a highly detailed model is profitable. PW suggests that while it's not a waste, extensive training is needed to work with micro-simulation (agent and activity based) models. Starting with population synthesis exercises and then incrementally introducing agent-based modelling elements is recommended.

PW mentions the shift towards agent-based modelling and its increasing importance due to changes in technology and new modes of transportation. We have ignored taxis in many models assuming they contributed little to congestion and mode choice. New Demand Responsive Transport, including Car clubs, car-sharing, shared ride, and on-demand mini-buses pose new modelling challenges. It is necessary to account for the size of the fleet, the level of service that effectively is offered at any one time, the organisation of the supply side (centrally or otherwise) and the new routeing patterns for ridesharing.

When asked about the advantages and limitations of AABMs, PW points out several limitations, including calculation time, the complexity of representing reality, difficulties in calibration, and the need for more assumptions. However, AABMs offer advantages at the micro-level, such as the ability to handle empty vehicles, model vehicle persistence, and address issues related to car ownership and mode shifts. These models can also help identify the critical mass required for new modes of transport, especially in rural areas, where subsidies might be needed to facilitate their operation.

Other

PW expresses uncertainty about specific advancements in the field, indicating a lack of adequate research instruments to fully grasp the intricacies of household decision-making. He suggests that understanding the decisions of individuals within households is important, but current instruments might not be sufficient for comprehensive modelling, especially as household complexity increases.

The conversation explores the idea of looking beyond the realm of transportation into fields such as psychology to better comprehend the complexities of household decision-making. The mention of stochasticity prompts a discussion about its role in modelling. PW explains that stochastic approaches are often used to address the uncertainties in future predictions, acknowledging the limitations of understanding the driving factors behind variability in models.

Regarding the impact of detailed transport models on decision-making, PW suggests that for policy development the use of activity/agent-based models could help identify advantages and potential pitfalls. However, he believes that for certain decisions like extending metro or bus lines, going into more granularities might not significantly enhance decision-making. The conversation touches on the use of AABMs for decisions related to spatial planning, like placing skyscrapers or new houses. PW indicates that while AABMs might not be necessary for all aspects of spatial planning, they could provide valuable insights, especially in situations influenced by changing factors like remote work policies, which an agent-based model could handle more effectively than a classic model.

In summary, the interview concludes by emphasising the need for ongoing interdisciplinary research, the challenges of understanding household decisions, the role of stochasticity in modelling uncertainties, and the potential applications of activity- and agent-based models in specific spatial planning scenarios influenced by evolving societal and policy changes.

5.3 Tom van Vuren

Tom van Vuren is director at Van Vuren Analytics and Visiting Professor at the University of Leeds.

Understanding and implementing AABMs.

TV, approaching this from the English perspective, usually sees activity-based models as a specific form of agent-based models. According to him, an activity-based model is likely to be implemented in practice through an agent-based approach, because the details and dimensions (such as motives, person characteristics (such as income) or destinations) can be filled in through agents. To distinguish between activity- and agent-based models, the abbreviations AcBM and AgBM are used.

Subtle but important distinctions are also made about the 'agents' in these models. TV believes that agents in this context are persons and not households or vehicles. If vehicles are considered agents, it becomes a different type of model that is more agent-based than activity-based (such as microsimulation).

JK introduces transport models as two-step models, where the first step focuses on creating matrices of transport demand (activity-based) and the second step deals with assigning this demand in a network. TV underlines this by mentioning that in England, the distinction between agent-based and activity-based is made by referring to 'activity-based demand modelling.'

TV acknowledges that there is significant overlap between activity-based and agent-based models, but that these terms are not interchangeable. JK and TV also discuss the role of 'pivot-point' models and how they can be integrated into both activity-based and agent-based models. TV sees a 'pivot-point' method as a possibility for an activity-based model that creates new HB tables.

Finally, it highlights the importance of a population synthesiser and an activity scheduler in these models, with TV suggesting that these serve as core components.

Data for AABMs.

TV stresses that while discrete choice models can serve as a basis, activity-based models require additional data for more detailed aspects such as activity planning and transport mode choice. He doubts that there is enough data to estimate these more complex models with sufficient reliability. He also reports that a 'time-use survey' exists in England, but it has only been conducted once (2015?) and is mainly person-based.

JK shows interest in this 'time-use-survey' and wants to know how it compares with the extensive range of household surveys in the Netherlands, such as ODiN (formerly OViN, MON and OVG). TV refers to Collins Teye of TfL, he has experience with this.
JK also questions whether big data can play a role. TV replies that big data is mainly used for basic matrices and that the potential of big data to feed more complex models is still untapped and needs further investigation.

Ethics also comes up, especially the issue of individual privacy in synthesised populations. TV sees less of an issue here because the data are synthetic. Both TV stresses that the data should be aggregated at a sufficiently high level to ensure anonymity, while also being sufficiently detailed for model precision. The Netherlands uses postcode-level data, and England uses Lower Super Output Areas, consisting of 400 to 1,200 households, as the modelling level.

TV highlights the need for detailed, reliable data for advanced transport modelling and the ethical considerations involved in using such data.

Challenges in developing and applying AABMs.

TV mentions that he has limited experience in this area, but he does point to some simple tests he conducted as part of a model for Brisbane. These tests included the introduction of a new public transport service and the extension of a road. The results of these tests are documented in an ETC paper (Zil et al, 2022), which can provide further insight.

TV indicates that, to his knowledge, there are not many activity-based models in the UK, outside those of TfL. He mentions models in Cambridge and Kent developed by PTV. In addition, he points to Arup's Smart Mobility Lab, which also works with agent-based models. The software used varies: PTV often uses their own software, which is based on ActivitySim, while Arup generally uses MatSim.

JK is advised to contact Arup, as they take a unique approach that may offer insights. Overall, the impression is that the field is evolving and that there are several challenges in both developing and applying such advanced models. There is therefore scope for both academic research and practical application and evaluation.

Future of AABMs

TV sees two possible directions for the development of these models. On the one hand, the industry could opt for a standardised approach, like how the four-step models are constructed. The principles and way of coding would then be similar, for example through the ActivitySim method. On the other hand, organisations can choose to each go their own way, experimenting with different approaches and discovering what is effective and what can be implemented in commercial software.

TV emphasises the importance of end-customer requirements. Should the models be easy to use with current investments, like with existing software like Cube or EMME, or are customers willing to invest in something completely new that better suits their specific needs? He notes that Arup seems to be going the latter route. They develop models to answer specific questions, rather than using a 'one-size-fits-all' model.

According to TV, a crucial question for the industry is how to develop and implement these models. The choice between a unified approach and a more diversified, experimental route is likely to depend on both technical considerations, available skills, and the wishes and needs of the end users.

Validation, complexity, and uncertainties of AABMs.

TV states that validation is mostly based on traditional methods, such as checking traffic flows, trip distance distributions and other common variables. However, he notes that he has rarely seen validation of new components unique to these models, such as the duration and quantity of activities. Internal validation, where the model gives the same output as the input, is one aspect, but TV argues that the real test lies in whether the model provides reliable and useful results when applied.

TV suggests that 'sensitivity testing' can help to gain more insight. This involves changing certain inputs or parameters to understand which aspects are most influential. As an example, he cites adjusting household structures or school hours, and how that would affect outcomes.

JK and TV also touch on the role of psychology and sociology in such models. TV notes that insights from these disciplines, as well as from economic theory, contribute to a better understanding of human behaviour and thus to the refinement of models. However, he also argues that current models are already complex and difficult to understand, creating a tension between the desire for more complexity and the ability to use these models efficiently. Adding more complexity would therefore only be justified if it also leads to better insights.

TV argues that a trade-off between complexity and usability is needed and stresses the importance of multidisciplinary approaches to improve these models.

Definition of study area, area of influence and outer area in AABMs.

TV claims that the approach to defining these areas is basically no different from that in 4-step models. He recommends following the same reasoning as is done in England. The study area should be the area most affected by the project's impacts.

TV points out the importance of defining what is internal and external to the study area. According to him, while traffic from internal to external can be modelled, traffic from external to internal probably cannot. This is because the external area has many variables that cannot easily be included in the model. Therefore, it should be treated as a preload or post load.

Furthermore, TV suggests that the question of using the same modelling techniques for these different areas depends on how quickly an activity-based model can be solved. The decision on what to model in detail and what not, could change based on available data and time. However, the general reasoning would remain the same.
TV believes that the basic principles of modelling these areas are like those of traditional 4-step models. While there may be different considerations, such as available time and data, the general approach should not be drastically different.

Choice of AcBM or AgBM.

TV initially recommends building neither unless one is sure that sufficient and reliable data is available. He points out the technical complexity of these models and questions whether those who want to build such a model sufficiently understand how they represent human behaviour (and whether there is enough data to prove this with sufficient conviction).

TV indicates that he sees these models more as tools for generating insights than as replacements for traditional 4- or 5-step models. He suggests that more detailed models lead to a wider range of predictions, especially when looking far into the future, considering many variables such as types of jobs, transport modes and government policies.

TV confirmed that these models could then be useful for developing scenarios. However, he also suggests better understanding what is going on before committing to building a complex model. TV stresses that current insights into human behaviour are more important for making decisions than complex predictions.

TV further points out the risk of basing future models on current behaviour, as behaviour changes or should change because of certain objectives. He suggests that it is better to work at a higher level of aggregation and conduct 'what-if' tests than to put all 'eggs in the basket of activity-based models'.

JK mentions that research shows that travel time seems to be a constant factor, based on 45 years of OVG, MON, OvIN, ODIN, suggesting that some behavioural aspects may be more stable than thought. TV acknowledges this but argues that this is more about generating insights within that aggregated behaviour than detailed predictions. Both agree that detailed models have their limitations and that there is much value in gaining insights into human behaviour.

Does the transition to more complex models result in better policies and decisions?

TV argues that the increase in model complexity does not necessarily lead to better outcomes in policy decisions. He argues that the fundamental economic principles supporting models - such as elasticity and travel time valuation - remain essentially the same regardless of the type of model used.

An important issue TV raises is the 'the model made me do it' phenomenon, where policymakers hide behind the complexity of a model to justify their decisions. This makes it harder to object to such outcomes, especially if a lot of resources have been put into the model. TV argues instead for a more nuanced approach that uses different streams of information to arrive at more informed decisions.

TV suggests making better use of existing techniques to gain a deeper understanding of various aspects, such as scenario analysis and alternative policy assumptions. He suggests that the focus should not be on the complexity of the model, but on the underlying assumptions and being open to multiple sources of information. This allows policy to be shaped in a more informed and nuanced way.

5.4 Andrew Daly

Andrew Daly is a professor emeritus at ASA Ltd.

Understanding of activity-based and agent-based transport models

AD asserts that the boundaries between different types of transport models are not strict. There are nuances and many grey areas. For example, he himself developed a tour-based model in Stockholm, incorporating complex household interactions and trip chains. According to AD, an activity-based model focuses on a household's movements throughout one day, while a tour-based model considers a journey from home to multiple destinations and back.

Regarding agent-based models, AD has less experience and therefore less to say. He understands that these models simulate behaviour at the micro-level, such as allocating a car among multiple individuals in a household. This is usually done through simulation, resulting in a clear outcome of expected behaviour. AD adds that he personally has not worked with microsimulations for assignment, such as dynamic assignment, but acknowledges that they could essentially be considered agent-based models. These techniques are applied in Copenhagen, although he has not been directly involved in that aspect of model development.

AD sees a lot of overlap and flexibility in categorizing transport models and emphasizes the role of simulation in agent-based models. He also recognizes the importance of the micro-level for understanding transport behaviour.

Data requirements for AABMs

AD explains that for activity-based models, the activity patterns of an entire household over a day need to be collected. This departs from traditional person-based surveys. A challenge here is acquiring reliable information, as every member of the household must be interviewed. AD also emphasizes the importance of recording activities that occur indoors, something often missing in existing data. However, this raises issues related to privacy.

AD further states that for a fully activity-based approach, models need to be expanded with data on telecommunications, such as e-commuting and online shopping. Additionally, he notes that working days have become more flexible after the COVID-19 pandemic, impacting the data collection process.

JK asks if surveys like the OVG (Onderzoek VerplaatsingsGedrag) are adequate, to which AD responds that they provide useful information but fall short in areas such as e-commuting. Instead, a 'time-use survey' over multiple days could be more useful.

On the topic of alternative data sources like mobile phone data and Floating Car Data (FCD), AD is cautious. He believes they provide strong timing data but lack sufficient information on, among other things, the motives behind movements, the modality, or characteristics of the traveller. However, a combination of traditional surveys and these new data sources could offer more insights.

Finally, response rate is mentioned. According to AD, there are issues with response rates and representation, especially when collecting 'value of time' data. People with a high 'value of time' are less inclined to participate in surveys, leading to biased data.

Demarcation of 'Study Area,' 'Influence Area,' and External Area'

JK emphasizes the importance of delineating these areas, especially when it comes to traffic passing through a study area but not starting or ending there. AD agrees, emphasizing that the definition of these areas largely depends on the policy being investigated.

AD adds that international traffic, such as traffic between Denmark and Sweden or the Netherlands and Belgium, poses a challenge. While detailed data is available on residents traveling to neighbouring countries, there is generally less information about foreigners entering the study area. Cooperation between governments in this regard is often limited, complicating modelling.

AS brings up the specific example of the Netherlands, where through traffic poses a problem for regional models. He argues that international cooperation is essential for more accurate modelling of these traffic flows. AD agrees but notes that he has seen few examples of such cooperation, except between Denmark and Germany and in the case of the Fehmarn Belt.

They agree that essentially two types of models are needed: one for the study area itself and another for relationships lying in the outlying area. They also emphasize the importance of defining these areas based on the policy being investigated.

Role of Stochasticity in AABMs

JK points out that stochasticity, especially in the use of Monte Carlo simulations, can affect the reproduction of model results. This is particularly important because the reproduction of some models may be legally regulated.

AD emphasizes that the use of 'seeding'—controlling 'random' numbers—can ensure reproducible results. He explains that some models work with semi-Monte Carlo simulations, making results similarly reproducible, although it may not be considered a true simulation.

A crucial point is that it's possible to perform multiple 'runs' and reproduce them separately. The key to this is using known 'seeds' for random numbers. If evaluating different scenarios, it's advisable to perform new 'runs' for all known 'seeds' instead of taking an average.

The issue of the time required to perform these 'runs' is also raised. AD acknowledges that this is an additional challenge, given the significant computational time that may be needed for such models.

Accuracy and Acceptance of AABMs

AD refers to his experiences with the COMPASS model in Copenhagen. He has written a scientific paper on this, along with Danish colleagues, discussing the validation of this model (see Overgaard et al., 2021).

The COMPASS model is compared to the longer-standing tour-based model in Copenhagen, named OTM. To AD's surprise, COMPASS performs better, especially in reproducing base-year traffic flows and possibly in elasticity and time distribution, though he's not entirely certain.

Regarding the detail of validation, the emphasis is on checking base-year traffic flows between regions and the distribution of trip lengths. It's mentioned that reproducing trip lengths in the Netherlands is often a challenge, a point that is also relevant to Copenhagen. AD notes that bicycle use in Copenhagen is similar to that in the Netherlands.

AD emphasizes the importance of being accurate in validation, and this is done at a high level of detail.

Advantages and disadvantages of AABMs

Advantages

- Policy Analysis: A significant advantage of these models is their ability to assess specific policy questions, something less efficient with a tour-based model.
- Daily Patterns and Households: These models are particularly suitable for analysing daily patterns and the effects of household members traveling together.
- Intrinsic Quality: According to AD, these models are intrinsically better and more credible than their counterparts.

Disadvantages

- Costs: Building such a model is time-consuming and requires specialized knowledge. For the project in Copenhagen, American expertise was even enlisted, increasing costs.
- Software Limitations: If one wants to stick to reasonable costs, they are often bound to existing software. In Copenhagen, American software DaySim was used, obliging them to follow certain choice model structures.
- Learning Curve: It takes time to build the necessary expertise, and according to AD, it will take several more years before Europeans can perform such work.

Other Remarks

- Validation: The models are fully validated and predominantly focused on passenger transport, including cars, public transport, and bicycles. Freight transport is not included.
- Learning Curve and Software: Obtaining suitable software is a cost factor, but learning to work with such models is also a challenge. Although there is much literature available, there are no extensive training programs.

Comparison of AABMs with trip-based and tour-nased Models

AD notes that in Europe, and specifically in the Netherlands, there isn't much experience with activity-based models, although there is interest. He suggests that if HCG had ever been tasked with developing an activity-based model, the situation in the Netherlands might have been different. An existing model called Albatross, developed by TU Eindhoven, is criticized as being 'impractical.'

AD suggests that transport models essentially consist of two parts: the demand for transport (which can be modelled using various approaches, such as activity-based or trip-based) and the assignment of this demand in the transport system. However, if data are aggregated before assignment, valuable information can be lost. Yet, opting for a disaggregated approach in the assignment requires a more disaggregated and agent-based demand model.

Interestingly, AD indicates that while Copenhagen has some experience with activity-based models, he's not sure what people there actually think of them. It's noted that there has been some reluctance to adopt these models in the Netherlands, possibly due to a lack of computing power, data, or even relevant issues necessitating these more complex models.

The future of AABMs

AD emphasizes that the development and implementation of such models depend on both the willingness and financial capabilities of agencies and government bodies. He notes that there are serious considerations to implement these models in the Netherlands and London, and in Copenhagen, it has already become a real model.

However, a significant hindrance is the time and money needed to develop such a model. AD points to the complexity of simultaneously maintaining two different models (the old and the new), which can result in a double financial burden. This, according to him, is a major reason why many agencies are hesitant. In Copenhagen, they were fortunate that the existing model did not require further investment and still runs in parallel with the new model.

In conclusion, AD states that the future of activity-based and agent-based models will largely depend on the willingness of agencies to make the necessary investments in time and money. Additionally, a certain flexibility in managing both old and new models could be a crucial factor in facilitating the transition.

Geographic Detail Level for Application of AABMs

The central question revolves around the appropriate application level of these models: regional versus national. AD believes that activity-based models may be better suited for regional issues. This is because these models provide a detailed description of behaviour, which is particularly important in issues related to local modes of transportation such as cycling and buses.

On the question of what exactly is considered 'regional,' AD explains that this can vary. It can be a major city and its associated influence area, but also a combination of urban cores with rural areas around them. AD adds that individuals' behaviour in relation to the size and nature of their city also plays a role. An example is Delft, a city whose residents less frequently venture beyond city limits than residents of other cities. This could be related to the size of the city and possibly the student population.

At the national level, other types of models are usually used, such as the tour-based model used in Finland. However, in Denmark, there is an effort to develop a national model at the tour level.

It seems that the appropriate geographic level for the application of activity-based and agent-based models depends on various factors, including the nature of transport issues and the specific characteristics of the region to be modelled.

Do more complex models lead to better policy decisions?

AD believes that more advanced models can indeed lead to better policies. As an example, he mentions the LMS, which, according to him, has revised the belief that investing in public transport solves all problems. The strength of a more detailed model, according to AD, lies in its credibility: it can convince officials and perhaps even politicians more because it aligns better with human behaviour.

However, there are also challenges. One of them is the 'black box effect': more complex models are harder to understand and may be less accessible to policymakers. Explaining such complex models in simple terms is a difficult task, but AD believes that the model should not be simplified more than necessary for an accurate representation of reality.

The shift towards more advanced models contributes to better substantiation of policy decisions, according to AD, but it also brings complications such as the accessibility and understandability of these models for policymakers.

5.5 Kurt Verlinden

Kurt Verlinden is a Research Leader at Significance.

Context and definitions

This section discusses the understanding of WS (Workshop) concepts of AABMs.

KV emphasizes that activity-based models focus on mapping the activity patterns of individuals and households. This approach begins with modelling a person's daily activities, such as working hours, shopping, and leisure activities. From these activities, movements are then derived.

KV explains that agent-based models represent a broader methodological approach. This approach not only considers activities but also looks into decision-making processes within households. He highlights that agent-based models portray individuals or households as decision-makers, enabling the analysis of decisions at an individual level. This is particularly useful in understanding complex dynamics in transportation demand.

KV explains that the term 'accounting' is important in developing these models. It refers to the need for detailed recording and consistency in decision-making. This 'accounting' ensures that all decisions, no matter how complex, remain coherent and logical. In the context of activity models, this plays a key role in ensuring consistent and conditionally correct choices at both individual and household levels.

KV also points out that despite their differences, activity-based models and agent-based models often closely align in practice. He illustrates this with the example of advanced tour-based agent models, which strongly resemble activity-based models. This demonstrates that the boundary between these models is sometimes blurred, and the choice of a specific approach depends on the complexity of the situation to be modelled.

Policy

This section focuses on the effectiveness of AABMs in supporting specific types of policies.

KV emphasizes that, although there is potential for diverse transport policies with AABMs, the practice in Flanders remains cautious. While the model there provides improved explanatory power, it is primarily used for traditional issues, such as adjustments to road infrastructure. However, KV highlights specific policy areas where AABMs can truly add value, such as spatial densification, demographic patterns, increasing retirement age, and increasing participation rates in employment. These models can analyse complex effects, such as population aging due to changes in participation and education levels.

Regarding forward-looking policy questions, such as autonomous vehicles and e-commuting, KV notes that many assumptions still need to be made. Models can illustrate the impact of different scenarios, but making accurate predictions about uncertain future developments remains a challenge. According to KV, making such predictions is unrealistic due to the many uncertainties and variables influencing these situations.

In the realm of broad prosperity and policy indicators, as seen in the Netherlands, it appears that in Flanders, this approach is less common. There is an awareness of the importance of looking at individual characteristics, such as income class, to understand who benefits from policy measures and who does not. Although it is possible to analyze these data quickly, it is not yet used as a major policy focus in Flanders.

Data

This section examines the data requirements and technical considerations inherent in AABMs, with an emphasis on the data dimensions needed for activity- and/or agent-based models.

KV emphasizes that detailed data is important for AABMs. Unlike traditional models using zonal data, AABMs require individual data from people and households. These data is essential to model the complex interactions between individuals and households, providing a more accurate and realistic picture of human behaviour in the transportation system.

KV points out that synthesis methods are available to generate microdata if complete data is unavailable. These synthetic data are an essential part of AABMs, helping model decision-making processes of individuals and households at a detailed level. By using synthetic data, researchers and planners can gain a better understanding of how people respond to different policy scenarios and transportation alternatives.

KV indicates that as AABMs become more complex, more detailed data is needed. For example, to model e-commute, researchers need to know which individuals work from home, what modes of transportation they use, and how this varies depending on different factors. Similarly, details such as parking facilities at work are important for accurately simulating people's travel behaviour. This specific information is important in refining models and addressing policy questions related to e-commuting, parking management, and alternative transportation options.

KV also asks about the use of modern data sources such as mobile data and floating card data. KV emphasizes that while these sources can be supplementary, they are not essential for building AABMs. If such big data is available with high quality, it can be used to enrich existing models. Using this data can help models be more realistic and accurate in their predictions. However, KV points out that the quality and reliability of this data are important and must be carefully evaluated before being incorporated into models.

In terms of privacy and ethics, KV notes that these issues have not been prominent in Flanders so far. Microdata is often anonymized to protect individuals' privacy. Nevertheless, KV is aware of potential privacy issues that may arise if specific individuals or households are inadvertently modelled. It is important to remain aware of these issues and ensure that individuals' privacy is always protected when using sensitive data for modelling purposes.

Methods

In this section, we aim to understand the technical details, focusing on the geographical scope, dealing with uncertainties, and model validation.

Technical challenges

- Microsimulation and stochasticity: The major technical challenge in building AABMs is dealing with discrete outcomes in microsimulation. Standard models work with percentages or shares, while microsimulation involves discrete decisions at the individual level. This requires randomization and introduces noise into the results. Methods have been developed to minimize this noise, but it remains a challenge.
- Model validation and reproducibility: Due to stochasticity, results cannot always be perfectly reproduced. However, techniques like using an initial 'random seed' ensure reproducibility. This seed generates a unique set of random numbers for everyone, ensuring consistent results.

Organizational challenges

- Transitioning to new models: Convincing clients to transition from traditional models to AABMs is a challenge. It requires investments in time and resources, and the outcome is not always certain. It is a leap into the unknown where success is not guaranteed.
- Data and population synthesis: Obtaining suitable data for microsimulation is a challenge. Using a micro population synthesizer can be a no-regret step to improve traditional data-derived models. It is important that the population remains realistic in future years and reflects changes in perceptions and behaviour.

Advice

- Big leap or gradual approach: The question is whether to make one big leap into ABMs or implement gradually. KV believes that a complete transition can be more effective, but it requires courage and commitment to achieve. A phased approach can be risky and lead to stagnation.
- Deployment of experts: It is essential to have an adequate number of experts skilled in building and maintaining AABMs. This requires an investment in training and development of staff.
- Population synthesis as a first step: Implementing a micro population synthesizer can be a logical first step to improve traditional data-derived models without directly transitioning to AABMs.

Other

In this section, broader questions are explored regarding the comparison of different modelling types and future developments in this field.

Firstly, the question arises of whether clients/contractors are ever advised not to use an activity-based model. KV acknowledges that this depends on the nature of the questions and the level of ambition in the evaluations. For small municipalities with limited questions and applications, such as reversing street directions or temporary closures, a complex activity-based model might be overkill. Instead, simpler tools can be used. Conversely, for large-scale projects and analyses aiming to predict behaviour changes, the use of activity-based models is strongly recommended.

Regarding the difficulty of working with activity-based models, KV emphasizes that methodologically, building activity-based models is like traditional models, but a change in mindset is required. While new, young experts can seamlessly transition to activity-based modelling due to their learned theoretical knowledge, experienced professionals may need to adjust their mindset. They must learn to approach issues from the perspective of individuals rather than aggregated segments.

Regarding costs, KV notes that models of similar complexity do not differ much in costs. For large-scale and complex projects, activity-based models and traditional models would incur similar costs. However, it is emphasized that building an activity-based model for small and simple applications may not be financially feasible. KV stresses that the ambition level of a project is the key factor when considering the use of activity-based models.

Regarding the impact of activity-based modelling on policymaking, KV notes that the new models are more nuanced and less sensitive to minor changes, such as increases in public transport frequency. Policy issues are now formulated in a more detailed and meaningful way, leading to refined and more effective policymaking.

Regarding the importance of data sharing, such as detailed population data from population synthesis, KV emphasizes that it is important to have a central database from which all research partners can draw to obtain consistent and reliable data. KV hopes for more collaboration and standardization in the approach to traffic modelling and data analysis among different partners and organizations.

5.6 Wolfgang Scherr

Wolfgang Scherr is owner and consultant at Moventes Gmbh.

Context and definitions

WS provided valuable perspectives on the distinctions between the two types of models. Agent-based models were described as intricate simulations of individual travellers, involving microscopic traffic dynamics. WS noted the challenge of defining stronger criteria for agents, requiring memory and learning capabilities from previous iterations, which influences model selection.

On the other hand, activity-based models were depicted as comprehensive simulations capturing both activities and travel journeys, offering a detailed view of individuals' daily plans. WS underlined the significance of modelling activities, their durations, and specific locations, shedding light on the complexity involved in these simulations. The concept of synthetic populations emerged as a critical element, demanding meticulous construction to ensure accurate representation in AABMs.

When discussing public transport within AABMs, WS highlighted the necessity of incorporating pre-existing data, including detailed timetables and future transport scenarios. These datasets are pivotal for accurate modelling, especially in predicting demand-driven developments in public transport systems.

Furthermore, WS addressed the role of households in AABMs, describing them as 'containers for persons.' However, they emphasised that households are not merely static entities but are dynamic in influencing behaviour. For instance, households with children often engage in activities like school runs or appointments, necessitating a nuanced understanding of these dynamics in behavioural modelling.

Data

WS describes the data aspects of AABMs. Various data sources are explored, starting with household survey data, which forms the basis for these models. To create a more nuanced representation, deep dives into time allocation throughout the day are necessary. The introduction of synthetic populations poses a challenge, especially in predicting future population movements and behaviours. Issues arise concerning car ownership, residential locations, and discrepancies between suburban and urban populations. While initial errors were made, iterative refinements were undertaken to enhance accuracy.

Regarding public transport data, collaboration between SBB and the government provided detailed timetables up to 2040, an asset for the project. The network intricacies were discussed, including bus stops and their direct connection to individual coordinates, bypassing zones, a choice made possible through the usage of MatSim software. Challenges were noted in modelling diverse points of interest such as museums and events. Defining these attractions by zones posed a workaround, although issues of granularity persisted.

WS also touched on data privacy and ethics. Privacy protocols necessitate a balance between data accuracy and individual anonymity. WS highlights the need to blur specific information, especially when dealing with households possessing unique attributes.

Methods

In this section, WS talks about the technical and organisational challenges inherent in developing and scaling AABMs for large-scale projects, particularly in the context of public transport (PT) and intermodal transport planning.

WS highlights several challenges faced during the application of agent-based simulation in real-world PT and intermodal transport planning scenarios. One major hurdle is the complexity of the approach, which demands significant staff time and specialised skills for internal research on methods and software development. The complexity also necessitates considerable computational resources, a challenge exacerbated by the relatively new and evolving nature of the software being employed. These factors contribute to prolonged computation times and introduce variability in the results. The variability stems from the fact that individual agents make decisions based on probabilities, and when different random seeds are applied, distinct outcomes emerge. This randomness, inherent in individual-level decision-making, poses challenges, especially when considering a vast number of variables in a country-wide model such as Switzerland.

WS explains that while aggregated models also faced similar challenges in the past, they have been addressed through years of refinement and adaptation. In contrast, the evolving nature of AABMs and their application in real-world scenarios means that these challenges persist, requiring ongoing adaptation and learning.

WS also discusses the inclusion of travellers from outside Switzerland in the model. These external travellers are simplified into agents and are considered alongside the Swiss population. However, their simulation, although present, is not as detailed as that of the domestic population.

About the variability of results, it becomes apparent that the randomness introduced at the individual agent level creates fluctuations in outcomes. WS emphasises the need for a nuanced approach to address this variability, especially concerning variables like the number of people boarding at different stations. Collaboration with PT organisations proved vital in managing this variability. By establishing a dialogue and sharing results, the modelers could validate their outcomes and explain the inherent uncertainties in the data.

Despite these challenges, WS underscores the value of transparency in the modelling process. It is important for modellers to communicate the limitations and uncertainties of their models to stakeholders. Acknowledging these uncertainties allows for a more realistic interpretation of the results and promotes a deeper understanding of the complexities involved in these advanced modelling techniques.

Other

In this part, the discussion centred on practical applications, challenges, and client management. When considering the cost of these models, WS noted that the development and application were approximately twice as expensive, a factor attributed to the complexity of the work. While some aspects were borrowed or replicated, a significant portion involved pioneering new approaches. The expenditure was not solely monetary; it also demanded a specialised team, making it important to find individuals with a unique blend of academic expertise and practical planning experience.

Regarding scalability, the project successfully leveraged cloud computing, allowing them to expand computational resources as needed. The model was stored in Europe, with external providers managing the infrastructure, notably through a contract with Amazon for a cloud server.

Maintaining the model posed challenges in terms of staff retention and knowledge transfer. Hiring individuals with the necessary background was difficult, often requiring training in practical planning methodologies. The team structure underwent adjustments, ultimately consolidating into a single team for both application and development.

When advising municipalities and governments on adopting activity-based and agent-based models, WS suggested a collaborative approach. Sharing data from the outset was highlighted as essential. He recommends starting with a pilot area for model build and calibration, expanding gradually as the project matured. Additionally, it was emphasised that using existing mainstream software, like MatSim, and contributing to its improvement and widespread adoption within the modelling community was important for the longevity and effectiveness of travel models. Sharing knowledge and avoiding isolated developments were seen as key strategies for ensuring the sustainability of travel models over time.

5.7 Luuk Brederode

Luuk Brederode is Transport Model Innovator at DAT.Mobility.

Context and definitions

This section explores LB's perspective on activity-based and agent-based models.

General

LB uses a framework to elucidate his views (see appendix). He has delved into literature on activity-based and agent-based models for transportation, basing his understanding on the work of Peter Vovsha.

LB emphasizes the importance of distinguishing between different 'units of mobility,' such as trips, tours, or complete activity schedules. In activity-based models, it is not just about the unit of mobility but also about other features like time-space consistency. In tour-based models, trips are part of a 'tour' where the start and end points of each trip match, enhancing spatial consistency. Activity-based models additionally consider the time component.

LB also discusses the difference between macroscopic and microscopic models. Macroscopic models use averages and estimates, while microscopic models are detailed, following the movements of individual 'agents' with discrete values. The Octavius model developed by Goudappel/DAT.mobility employs microsimulation, but it does not fully embrace activity-based modelling.

Octavius's limitation is its disregard for variable arrival and departure times for activities, omitting bottlenecks caused by delays in daily activities. Activity-based models consider the entire daily schedule of an individual, including dependencies between different activities throughout the day.

Activity-Based and Agent-Based Models

LB sees activity-based models as an approach focusing on the unit of mobility (trip, tour, etc.), considering time-space consistency of activities and mobility patterns. It goes beyond modelling trips as it considers the influence of delays and other variables on individuals' entire activity schedules.

Agent-based models are relatively new in the field of transport modelling according to LB. Originating from computer science, these models integrate self-learning behaviour of agents in the system. Unlike activity-based models, where behaviour is predefined, agent-based models can generate a range of future scenarios based on interactions between agents.

LB notes that the two types of models serve different purposes. Activity-based models are more oriented toward predicting the most likely future scenarios based on specific input. Agent-based models are more exploratory, generating a range of possible futures, which can then be tested against a vision or goal.

LB states that choosing between activity-based and agent-based models depends heavily on the goal: predicting likely outcomes or exploring a wide range of future possibilities.

Understanding 'Agent'
There is some confusion about what 'agents' precisely mean in the context of traffic and transport models. JK is curious about 'agents' and how they relate to 'population synthesis.'

Regarding terminology, LB acknowledges the confusion, suggesting a focus on the content rather than labelling of models. LB sees more application currently in activity-based models and suggests that agent-based models should be considered mainly if there is a specific application within the field.

LB asserts that the concept of 'agent' is broader than often assumed in traffic models. According to the original definition in computer science, agents can also be objects (e.g., a server in a computer network) as long as they exhibit a certain level of intelligence and goal-directed behaviour. LB believes that the traffic modelling community has embraced a limited interpretation of what 'agent-based' modelling is, often confusing it with 'activity-based' models.

Regarding the role of autonomous vehicles, car-sharing, and bike-sharing as 'agents' in these models, LB indicates that these forms of mobility can indeed be considered as agents. However, he emphasizes that he is not an expert in agent-based modelling.

LB notes that the terms 'activity-based' and 'microsimulation' are often used synonymously for 'agent-based' models, simply referred to as AgBMs. LB stresses the importance of specifying clearly what is meant by an 'agent-based model' in a proposal because the terms do not always carry the same meaning, posing risks. LB adds that three factors must be named to clarify what an AgBM is: the content of mobility, the aggregation level of individuals, and the nature of the parameters and choice models used.

Data

This section describes LB's perspective on data for activity-based models.

General
LB explains that data needs depend on the type of model one is focusing on. Compared to aggregated models like 'trip-based' models, more detailed models have a more complex data requirement.

For traditional aggregated models, mainly simple information about the population and car ownership is required. These data are used for segmentation, such as distinguishing between people with and without cars. Additionally, variables on the destination side, like job or school locations, are often relevant.

For more detailed models like activity-based or agent-based models, more segmentation is required. LB mentions hundreds of segments arising from the combination of different variables like age, income, and societal participation. LB highlights that only the CBS (Statistics Netherlands) has access to this detailed data. These data are privacy-sensitive and may not be used outside the CBS servers.

LB emphasizes the importance of 'population synthesizers,' especially when transitioning from macroscopic to disaggregated or microscopic models. These synthesizers are important for generating detailed population segments in each zone covered by the model. They are essential for predicting future scenarios and are already used in existing systems, although LB questions their quality.

Population Synthesis
Performing 'population synthesis' requires so-called 'seed data.' The data for population synthesizers often comes from surveys, indicating the initial distribution across different segments. Additionally, 'margins' or totals are needed at the zonal level for each variable, such as the number of men and women or age groups. These 'margins' are essential for scaling the segments to the correct level.

Regarding the selection of variables, LB states that it depends on the underlying choice models in the transport model. Variables that are significant in explaining choice behaviour must be known within the population and included in the 'population synthesis.' This requires not only good socio-economic data but also detailed survey data. LB points out that complications may arise if the definitions of variables do not match in different data sources, or if certain variables, such as income, prove to be insignificant in the dataset used.

Cadastre Data
LB emphasizes that, although cadastral data can be useful in providing an insight into household income through property value, there are inherent limitations. The main issue is that for cadastral data, there is no 'seed' (from survey data) establishing the necessary nationally representative distribution of property value concerning other population variables. In other words, there is no data on how property values correlate with other characteristics such as age or gender.

LB adds that for 'population synthesis,' the selected variables must be available not only in both survey data (for the 'seed') and spatial data (for the 'margins') but also that inclusion in the population synthesizer makes sense only when variables are explanatory for one or more of the behavioural choices being modeled. He indicates that not all available variables are necessarily relevant to, for example, mobility behaviour (or have strong intercorrelation).

Points of Interest (POI)
The relevance and possible use of POIs in transport models are discussed. Models often focus on work and school locations, but a significant number of people also travel to a POI such as hospitals, museums, and events. The question is how to incorporate that into these models.

LB responds by first addressing the traditional approach via gravity models, which apply certain restrictions and corrections based on costs and attractions. He indicates that these models provide a 'one-way approach' to adjusting predictions based on constraints. In more advanced models like decision trees and choice models, this direct correction is less straightforward, necessitating adjustments to the underlying choice model.

Regarding POIs, LB suggests using specific access mechanisms for 'special' locations, such as museums or hospitals. He mentions the concept of 'specific constants' added to the choice models. He also refers to this as 'regionalization.' This method allows integrating market shares or observed distributions, such as travel distances or transport choices, into the model, thereby directing more people to a particular POI.

Household Surveys and Panels
Dutch household surveys do not include activities that are specifically indoors, such as e-shopping and e-commuting. LB suggests that household characteristics are already included in the choice models but may not be sufficient. He notes that it would be useful to estimate a choice model based on current data to identify any missing elements. He refers to the graduation project of Stella van Lent, which might be relevant.

Other
This section addresses miscellaneous questions such as challenges and steps to be taken.

Challenges
LB sees both technical and organizational challenges in developing and applying activity-based transport models. LB describes the experience from Goudappel/DAT.mobility in the technical development of such models. They have developed an expandable framework where new choice models can be added, providing flexibility.

An important organizational point is customer acceptance. According to LB, customers are accustomed to macroscopic models that generate extremely stable outcomes. Micro-models (including activity-based and agent-based models) introduce a certain level of 'noise' or variability, which customers are less inclined to accept. LB notes that this 'issue' has been partially addressed by them through the introduction of 'frozen randomness'; locking the seed values.

LB indicates that their current approach is a form of simulation but emphasizes that the 'noise' is still present and should be recognized from a policy perspective. This is also the case in practice, where day-to-day variation is encountered.

LB finally emphasizes the importance of awareness around these issues. He believes that there is likely to be no change in the way models are applied and understood by policymakers and customers in the short term. However, if these issues are not identified, the chances of them ever being addressed are even smaller. We must continue to advocate for innovations not only on the model side but also on the policy side.

Development toward Activity-Based Models
LB emphasizes that traditional models still have their utility and that the transition to more advanced models is not always necessary, depending on the goals.

LB further states that the delay in the development of AcBM is because there are no client inquiries, not necessarily because they are not advanced in development. If specific questions arise, such as the introduction of a Hyperloop, a choice model based on preference data must first be developed. As long as such questions are lacking, there is little motivation to invest in more complex models.

Regarding no-regret steps, LB suggests adding a 'population synthesizer' to the current strategic models as a logical and useful first step. This can be applied immediately and helps organizations acclimate to more advanced models.

Concerning the transition from traditional to activity-based models, LB highlights the importance of 'microsimulation' to incorporate travellers' decision-making context. This allows modelling dependencies between different travel decisions. LB points out that, in developing their current model, Octavius, they deliberately took an intermediate step and did not transition directly to a fully activity-based model. This is because a complete shift to activity-based modelling would require a significant paradigm shift.

5.8 Leonid Engelson

Leonid Engelson is Transport analyst at the Swedish Transport Administration and Guest Professor at the Linköping University.

Sampers

General

Sampers is a national model for Sweden, comprising five regional models and one long-distance model. The regional models cover trips up to 100 kilometres and include car modes (driver and passenger), public transport, bike, and walk. The five regional models share the same structure and coefficients (with few region-specific dummies). The long-distance model focuses on train, bus, flight, and car travel. This model has been developed independently of the regional models, with distinct demand models for long-distance travel.

The primary application for the long-distance models is railway projects, particularly high-speed rail, and other railway projects in Sweden. However, Sampers is not used for bike or walk infrastructure development, primarily for car and public transport projects. JK drew a parallel to the Netherlands, where there are four regional models and a national model, but this is not a long-distance model. The primary differences between the models are the estimated coefficients and input data; otherwise, they share the same principles and software.

When asked about whether Sampers is trip-based or tour-based, LE explained that it's based on round trips. Before estimation, travel surveys are simplified to eliminate intermediate stops, defining the main purpose of the trip based on the location where the person spends most of their time. This approach is applied to both regional and long-distance models.

LE also addressed the division between domestic and international trips. Currently, international trips have a fixed matrix, especially for railroad trips. There is limited international trip data, but ongoing development aims to include long-distance international trips in the model.

Regarding cooperation with Copenhagen and the Compass model, LE mentioned some data exchange, but the cooperation is not very close. The collaboration is at a more aggregate level, indicating room for potential development in the future.

Main policy objectives of the model

LE explained that Sampers is primarily used for infrastructure development, particularly for public transport, with a focus on railway and road network projects. However, it is also employed for policies, such as congestion charging and tax deductions for work-related trips. One noteworthy aspect is Sampers' capability to conduct distributional analysis, assessing the impacts of policies and projects on various demographic groups. This ability was a key instrument in convincing the administration to support the recently completed project (Sampers 4) where the regional demand models have been re-estimated and implemented in a disaggregated fashion.

LE noted the limitations of Sampers in addressing certain emerging challenges, such as self-driving vehicles, as it requires more sophisticated capabilities related to trip chains and departure time choices. These factors are important for local governments but are not currently a focus of the model, which primarily serves the interests of Sweden as a whole, particularly for national planning and ranking of projects.

The discussion also touched on cooperation with governmental organizations at different levels. LE explained that cooperation involves data sharing and network validation, but when it comes to the specific needs of municipalities, particularly concerning bike infrastructure, many municipalities develop their own models, which can differ from the national model's approach.

Regarding activity-based modelling, LE confirmed that it is not widely used in Sweden for operational purposes but is mainly a subject of research at universities and research institutions. The governmental body follows these research projects and provides grants but does not have operational models that employ activity-based modelling.

Context and definitions

LE explained that Sampers is a step towards AcBM, as it is agent-based. The model is based on a synthetic population, and it considers all choices related to trip generation, destination, and mode choice for each individual agent within the synthetic population. However, he clarified that while it can be considered a step towards AcBM, it still operates as a four-stage model.

JK sought further clarification on LE's understanding of activity-based models and agent-based models. LE acknowledged the ambiguity in terminology and expressed the need to define these concepts based on international modelling practice and research. In the context of Sampers, they consider it agent-based because they use the term "agent" when discussing the choices made by individuals. Agents, in this context, refer to individual decision-makers. LE clarified that Sampers primarily focuses on individual decisions and does not consider household decisions, even though they consider household characteristics such as the presence of a car or the number of children when modelling individual choices. Household needs do not drive the decision-making process in the model.

Modelling

Population synthesizer

LE began by describing how they synthesize the population, ensuring that all individuals have socioeconomic properties and a designated base location. They run the model based on these properties and assess various alternatives for trips. He clarified that when running the regional model, they focus on the population within that region and the buffer area, as some trips originate from neighbouring regions within 100 kilometres. The simulation includes each individual from the core region and each other individual from the buffer, with the results for the latter multiplied by two.

Regarding the simulation process, JK inquired whether it is performed once or multiple times, such as in Monte Carlo simulations. LE clarified that they do not employ Monte Carlo simulations. Instead, the Gumbel distributed error terms are generated for each simulated choice, and the alternative providing the highest sum of the systematic utility and the error term is chosen. However, the simulation occurs several times due to feedback iterations. The model goes through iterations of simulating behaviour, applying the method of successive averages to calculate travel times, which are used in the next iteration of the demand model (via new skims). The number of iterations varies based on convergence. Mostly it is about five times.

Overlap with Dutch model
The discussion highlighted similarities between Sampers and Dutch national models, likely due to shared contributors. JK also inquired about the feedback loop, which LE confirmed returns to the trip frequency, mode, and destination choice models and not the population synthesis stage.

Randomness
JK raised the issue of random noise in small-scale projects, particularly when focusing on individual bus stops or lines. LE acknowledged the presence of random variation but stated that it doesn't significantly impact cost-benefit analysis for large-scale projects, which Sampers is typically used for. However, he noted the importance of considering such variation, especially at smaller levels, such as municipalities, where bus stops become crucial.

In the model every agent makes a discrete choice. There is one random seed for each choice model used to distribute the errors for all agents. We calculate the random error terms on the fly. For comparing scenarios, we make sure to use the same seed.

Data

Travel survey data
LE emphasized the importance of high-quality data, particularly travel survey data, and highlighted the challenges they face with diminishing response rates, which may lead to biased data. The interview touches on the complexities of modelling activities, especially in a changing environment where remote work is increasingly common. While they have some models in research addressing these complexities, they admit that there is much work to be done.

big data
The interview also explored the use of big data, including GPS data, and its limitations, such as accuracy and the need to recruit individuals. They discussed the potential of using smart card data from public transport, but challenges remain in understanding where people disembark from the transport.

Regarding data integration in Sweden, the focus is mainly on combining census with travel survey data for synthetic population generation, but they are yet to fully leverage the potential of big data sources.

LE suggests that activity-based models may be more relevant to cities and municipalities, given the complexities and the diversity of activities in urban areas. Rural areas, with simpler travel patterns, may not require the same level of modelling detail. LE also emphasizes the significant organizational and conceptual challenges when transitioning from aggregate to disaggregate modelling, indicating that a stepwise approach, such as a hybrid model, can be more manageable.

Other

User-friendliness

LE emphasized the importance of user-friendliness in their models, given that they are used by numerous consultants and other organizations. While LE acknowledged the advantages of activity-based models, he highlighted the challenges they face, such as data quality and the need for high-quality modelling. He noted that the transition to activity-based models is not currently a priority, as the existing model, Sampers 4, meets their requirements, and their focus is currently on improving the long-distance model.

Time consumption

LE mentioned that the development of agent-based models did not take an extraordinary amount of time, but the challenge remains in educating consultants on using the model effectively. Compared to the previous versions of the model, the demand computation takes shorter time which allows to increase the number of assignment and feedback iterations, hence tighter convergence, and more reliable results. He expressed 'no-regret' about implementing population synthesis, emphasizing that its success is contingent on data quality. He also noted their collaboration with INRO (now Bentley) and the complexities of reconciling different zonal definitions across various regions.

5.9 Kay Axhausen

Kay Axhausen is Professor at ETH Zürich.

Context and definitions

KWA views activity-based models on one hand to generate demand, primarily implemented as large-scale nested logit model structures. On the other hand, he sees agent-based models as focusing on creating synthetic populations to simulate demand and integrating traffic flow elements and demand response for feedback between demand and supply. In contrast, classic activity-based models aggregate their demand and feed it into assignment models, either static or dynamic.

The modelling process can be split into two steps: transport demand modelling, which results in matrices, and traffic or assignment modelling, which leads to loaded networks. KWA states that agents play a crucial role in both steps, from population synthesis in transportation demand to microsimulation and dynamic assignment in traffic flow models. This way, there is consistency between throughout the system.

KWA addresses the computational challenges associated with agent-based models, especially regarding traffic flow simulations, which can be slow due to their complexity and scale. KWA highlights that the computational time is a trade-off for more accurate and comprehensive modelling, while faster results might require exclusion of certain services or aspects from your model.

In terms of terminology, KWA mentions that in the literature, activity-based models are sometimes referred to as AcBM, and agent-based models as AgBM. However, he believes it's not necessary to impose new nomenclature on these models and suggests that authors can use the abbreviations they prefer, as long as they differentiate between the two modelling approaches.

Data

General

KWA highlights that he doesn't believe that activity-based models necessarily require more data than traditional four-stage models. Both approaches start from a similar base, and additional data requirements arise mainly for modelling shared services and new transportation options which did not exist 20-25 years ago. He emphasizes the need for operator's data on service levels and price differentiation by time-of-day, which were not as relevant in the past.

Household surveys

KWA suggests that household surveys can be challenging. He particularly addresses surveys in the US and England, where household participation in the survey is declining. He recommends shifting from trip-based surveys to stage-based surveys to capture more detailed information. In stage-based surveys, trips can be regarded as a series of stages between two activities. It can also be seen as the 'legs' of a trip-chain.

Panels

Regarding using panels, KWA suggests that surveys today must acknowledge the self-selection bias involved in who chooses to participate. For rigorous statistical analysis, he hints that methods should account for such biases, mentioning the Heckman selection model as a potential approach.

Costs of data collection

Finally, KWA brings up the economic implications of data collection. He elaborates on a Swiss study involving GPS tracking that cost nearly half a million euros (MOBIS), pondering if the incentives offered were too high. Both agree that determining the optimal incentive is complex, as the same amount might mean different things to different people, thereby potentially introducing bias. Still, in terms of costs per person days tracking studies can be cheaper and more complete than CATI surveys.

KWA underscores the evolving challenges in data collection for transportation models and the importance of adapting data collection methods to the changing landscape of survey participation. KWA emphasizes the need for empirical research to determine the right balance between response burden and incentive payments.

Data for activity scheduling

KWA acknowledges the complexity of capturing data related to activities, particularly with the rise of remote work and online shopping. He suggests that a time budget survey, which tracks when and where people work, shop, and engage in other activities, would be necessary to gain a comprehensive understanding of travel behaviour. Time budget surveys have been conducted for many years by sociologists, and modern implementations are transitioning towards computer-based and smartphone-based approaches.

KWA describes a study called "Time Use Plus," in which participants were recruited and used a smartphone app for data collection. The app tracked GPS data and collected information about time use, travel, and expenditures. This hybrid approach aimed to bridge the gap between traditional time budget surveys and travel behaviour data. It also included a final interview to capture irregular expenditures.

Concerning participant drop-out rates due to the involvement of the survey and time constraints, KWA points out that these challenges are common in survey-based research and are not unique to collect GPS data.

Privacy and ethics

KWA then touches upon privacy and ethics concerns. He explains that the Time Use Plus study obtained ethics approvals and addressed concerns by ensuring that participants understood the data collection process and the potential sharing of data with third parties for analysis. Consent and transparency were important elements of the ethical considerations.

Big data

Finally, KWA discusses the use of big data sources and combining them with survey data. KWA mentions that many efforts have been made in this regard and emphasizes the need for standardized methods for combining data sources, especially in a country like the Netherlands. He suggests a centralized effort to create the best possible artificial population and share it across various agencies to ensure data quality and consistency.

Methodology

Population synthesis

KWA suggests the idea of creating a national population synthesis model that provides basic information about individuals, such as their locations, workplaces, age, education, and profession. He emphasizes the importance of this foundational model as a common base for various transportation models. However, he also acknowledges that local authorities may need to tailor additional demand generation components to account for localized differences.

JK points at the hierarchical modelling approach in the Netherlands, where different regions have their own models within the broader national model system. KWA mentions a similar practice in Switzerland, where a national model with 10,000 zones serves as a basis, but larger cantons and local authorities create finer models for their specific needs.

Activity scheduling

JK raises the question of whether activity-based modelling should be conducted at the city level, with detailed activity schedulers. KWA agrees, suggesting that the rise of remote work makes schedule-based models more relevant. He also highlights the challenges of modelling carpooling and the need to consider the interactions within households and between individuals.

Stochasticity

Regarding the stochasticity of the activity-based models, KWA explains that ensemble runs of models like MatSim can yield relatively consistent results at the link level. However, he emphasizes the importance of documenting processes and standardizing demand generation to enhance reproducibility.

Accuracy and tolerance

Finally, KWA touches upon the accuracy and tolerance of modelling results. KWA suggests consulting with the Swiss Federal Railroads (SBB) to gain insights into how practical planning studies handle this aspect. KWA's perspective highlights the complexity and nuances of transportation modelling methods, especially in the context of population synthesis, demand generation, and model reproducibility.

Advantages and limitations

MatSim

KWA highlights the advantages of models like MatSim, where demand generation and traffic flow are fully integrated. This integration naturally yields dynamic results and allows for the incorporation of shared services and the generation of credible metrics related to crowding and congestion. The consistency in valuations between different facets of the model, such as mode choice and assignment, is a significant advantage. However, these benefits come at the cost of extensive computing times due to the model's complexity.

Challenges

KWA addresses challenges of the user interface, acknowledging that the interfaces for open-source models like MatSim are not as user-friendly as those from commercial firms. Nevertheless, he mentions that efforts are underway to improve the accessibility of these models through cloud-based interfaces.

Concerning the computational aspects of running large-scale models like MatSim, KWA observes that despite technological advancements, the computing time has largely remained constant. KWA clarifies that they now use cloud-based, multi-core server architecture, which allows for scalability. However, he notes that while many elements of MatSim have been parallelized, the traffic flow component remains a bottleneck as it still runs on a single core. Efforts are underway to parallelize this aspect, aiming for a more efficient and quicker computational process while maintaining the code's integrity within the open-source environment.

Future developments

When it comes to the future of activity-based models, KWA mentions advancements in modelling the entire day's utility measure more effectively. This involves modelling the path through time and space as a uniform utility function, making the modelling process simpler and more straightforward. Another advancement is the improvement of social interaction models, allowing for better understanding of group formation and joint decision-making, particularly in scenarios like carpooling or taxi usage.

Complexity versus policy

Finally, KWA touches on the question of whether the move from trip-based to activity-based modelling will lead to better decisions and policies. KWA suggests that while highly detailed models are essential for some operations, there's a case for direct demand models that use observable data and land use information to make predictions without requiring highly detailed surveys. He also highlights the importance of having consistency between different modelling levels, considering whether certain highly detailed models are needed on a national or local level based on specific policy needs and objectives.

5.10 Peter Vovsha

Peter Vovsha Principal Scientist at Bentley Systems and Vice President of INRO.

Context and definitions

PV provided valuable perspectives on the distinctions between the two types of models.

Activity-based models (ABMs)
ABMs, as discussed in the interview, are models that start with activities, from which tours and trips are derived. The interviewee emphasized a critical distinction between tour-based models and true activity-based models. They pointed out that many models claiming to be activity-based are, in fact, tour-based models implemented in a micro-simulation fashion. True AcBMs, especially those classified as third generation, delve deeper. They begin with synthetic populations, predicting what activities people are interested in. These activities are then combined into tours, and scheduling decisions might be made at the level of activities or later when tours are formed. The interviewee highlighted the complexity of classifying activities and purposes, particularly in joint and individual contexts. For example, joint activities, like family outings, differ significantly from individual activities such as grabbing a quick snack. Furthermore, they discussed the detailed segmentation of activities in advanced AcBMs, even distinguishing between breakfast, lunch, and dinner due to varying behaviours.

Agent-based models (ABMs)
The conversation then shifted to Agent-Based Models. The interviewee explained that the definition of agency is rooted in computer science, involving models that represent individuals with specific properties, such as intelligence, learning, and adaptation capabilities. They discussed the challenges associated with defining agents, especially in the context of emerging technologies like autonomous vehicles. The interviewee also highlighted the role of agents in shared mobility, where vehicles themselves, transportation network companies, and even trip planning services can be considered agents. They emphasized the complexity of distinguishing between various types of agents and the decisions they make, whether it's a person behind the wheel of a car or an algorithm guiding a shared mobility service.

Evolution of models
The interview concluded with a reflection on the evolution of AcBMs. It was noted that models have progressed from simpler tour-based approaches to more sophisticated, third generation AcBMs. These advanced models consider intricate details of activities, trips, and agents, providing a comprehensive understanding of human behaviour in transportation contexts. The interviewee pondered whether European models should follow a similar evolutionary trajectory, gradually incorporating complexities, or take a more direct approach to embrace advanced AcBMs, acknowledging the challenges associated with both paths. In essence, the interview provided valuable insights into the nuanced world of transportation modelling, highlighting the intricacies of activity-based and agent-based approaches while considering the evolving landscape of transportation technologies and user behaviours.

Data

This section aims to examine the data requirements and technical considerations intrinsic to these models, focusing on what data (dimensions) are necessary for activity- and/or agent-based models.

Data requirements

- Household travel surveys: The foundation of activity-based models relies on comprehensive household travel surveys. Initially, these surveys included all members of a household, observing joint travel and other activities for at least one day. However, advancements in data availability, such as national travel surveys in the United States, have reduced the necessity for extensive new surveys. Donor models, based on existing data, are often used as a starting point.
- Time-use surveys: These surveys provide insights into 24-hour activity patterns, although they are challenging due to respondents' difficulties in recalling and reporting their activities accurately.
- Work-from-home activities: Special attention is given to at-home activities, especially work-from-home scenarios. Models include e-commuting frequency as a crucial factor, reflecting the increasing trend of remote work.

Utilising big data

Advanced machine learning: Activity-based models can be built or calibrated using aggregate data and advanced machine learning methods. big data sources, such as traffic counts from services like Streetlight or AirSage, provide valuable insights. These sources employ various technologies like GPS, cell phone tracing, and apps to collect data.

Ethical considerations and privacy

Strict privacy laws are respected, ensuring that individual data remains confidential. Personally identifiable information is removed before making data publicly available. Privacy is maintained both in public datasets and during internal use for planning purposes.

Challenges and advances

- Changing survey formats: The transition from phone interviews to app-based surveys has revitalized response rates, making data collection more efficient and user-friendly.
- Balancing costs and accuracy: While recruitment efforts are time-consuming and costly, they are important for ensuring representative data. Efforts to simplify surveys and maintain respondent engagement are ongoing challenges.
- Adapting to remote work trends: The rise of remote work, especially post-COVID, has become a significant factor in modelling. Predicting and understanding these work-from-home scenarios are vital due to their substantial impact on commuting patterns.

In summary, data collection for activity-based models involves a mix of traditional surveys, advanced machine learning techniques, and strict adherence to privacy regulations. Balancing the need for comprehensive data with respondent privacy and survey efficiency remains an ongoing consideration in the development of these models.

Methods

In this discussion, PV provides detailed insights into the integration of machine learning methods in transportation modelling:

Machine learning as an extension of econometric methods

PV emphasises that machine learning is not entirely new, but an extension of existing econometric methods used in transportation modelling. He compares machine learning techniques like neural networks to traditional econometric models like logic models and logistic regressions. He stresses that understanding discrete choice models in econometrics provides a strong foundation for comprehending machine learning methods.

Practical application of machine learning

PV highlights the practical aspect of learning machine learning. He suggests that theoretical knowledge alone is insufficient; practitioners should actively apply machine learning methods. He recommends focusing on understanding neural networks, decision-making trees, and random forests. These are fundamental components of machine learning that can be applied in transportation models.

Gradual integration and experimentation

PV advises integrating machine learning techniques incrementally into existing transportation models. He recommends using an approach where practitioners start with their current model and gradually incorporate machine learning features using platforms like agent-based modelling tools. This incremental approach allows professionals to learn and adapt as they progress, preventing overwhelming complexity.

Communicating complex models

PV addresses the challenge of explaining intricate machine learning models to clients. He suggests finding simple and relatable language to convey complex concepts. Analogies and metaphors can be used to make the explanation more accessible, ensuring that clients, even those without a technical background, can grasp the essential aspects of the models.

Embracing machine learning for the future

PV emphasizes the inevitability of machine learning in the future of transportation modelling. He stresses that professionals who do not adopt these advanced methods risk falling behind. He encourages practitioners to proactively engage with machine learning techniques, adapt their existing models, and keep learning to stay ahead in the field.

Overall, PV's insights underscore the importance of practical application, gradual integration, effective communication, and continuous learning when incorporating machine learning into transportation modelling practices.

5.11 Collins Teye & Tim Price

Collins Teye is Strategic Analyst at Transport for London and Tim Price is Demand Forecasting Manager at Transport for London.

AB Motion

CT and TP explained that TfL has transitioned from an older demand model (LTS) to Motion, which is a four-stage model encompassing tour generation, mode and destination choice, and assignment models. Motion is unique in that it is linked to synthetic population data, allowing for more robust segmentation and policy analysis. AB Motion, on the other hand, is an advanced activity-based model that operates as a separate model but is connected to the traditional traffic assignment models. It produces travel plans for each agent, providing rich data on their activities, locations, arrival times, and mode of transport.

CT clarified that the key difference between the traditional model and the activity-based model is the output: the traditional model generates trip matrices, while AB Motion produces travel plans for individuals, bridging the gap between trips made and the people making them.

Regarding the production of travel plans, CT mentioned that the scheduler is responsible, but there are various ways to generate these plans, with methodological innovations playing a crucial role. These innovations involve the use of discrete choice models, audit logic, probit models, and entropy to model different components of the plan, such as departure times and activity durations. Simulation comes into play when decision-making is based on choice probabilities, making the results reproducible with slight variations when changing random seeds.

Overall, TfL has integrated an advanced AcBM paradigm into its modelling framework to address complex policy questions, especially those related to pricing, public transport usage, and understanding individual travel behaviour. The models are designed to be highly flexible and capable of producing comprehensive, reproducible results to support decision-making processes.

Reproducibility

AS raised a concern about how to ensure that changes made to the model accurately reflect policy effects, especially when different random seeds are used. CT explained that when the random seed is fixed, the changes in the model reflect the changes made in the policy. This approach ensures consistency when testing policies, as the seed remains the same.

AS then asked whether using different seeds in scenarios with a base year and a policy change would yield comparable results. CT clarified that maintaining the same seed in all scenarios would be ideal for consistency. However, when using different seeds, the results would still be consistent but slightly different. He emphasized the probabilistic nature of modelling, where predictions are based on probabilities. Thus, the differences arise due to variations in individual choices over multiple model-runs.

Travel plans vs OD-matrices

When JK inquired about the types of OD matrices being built, CT emphasized that the translation and assignment depend on the tools and capabilities available. In an ideal world, travel plans can be directly assigned to the network, a process MatSim facilitates. However, their organization doesn't have such a model, and there are reasons for this that they plan to discuss later.

In the absence of a MatSim-type model, CT described their approach. Travel plans are converted into matrices, and these matrices are assigned to the network. The flexibility of this process allows them to create various types of OD matrices based on project needs and available resources. They can choose between traditional peak and off-peak matrices or more detailed hourly assignments, depending on the project's requirements. In their current setup, they use four matrices: AM peak, inter-peak, off-peak, evening peak, and off-peak. Each matrix represents a specific time period, and travellers within that period experience similar travel times.

CT confirmed that they employ traditional assignment techniques for this process. The choice of OD matrices and the level of granularity in assignments are determined based on project goals and policy considerations.

Data

CT highlights that TfL collects rich household survey data annually, which serves as a crucial data source for their activity-based demand model. The household survey data has been collected since 2005, providing extensive information on travel behaviour.

Additionally, CT mentioned that they borrow data and networks from the traditional models for their activity-based model (ABM). However, there are differences in how they use the data. While both the traditional model and AcBM use the same household travel or activity diary, the AcBM focuses on reproducing the travel plan of everyone, capturing detailed trip plans.

Regarding in-home activities like working from home or e-shopping, CT acknowledged that their current data does not model these activities. They aim to improve the data by incorporating such information into the survey, but this process is still in development. While they have discussed the possibility of using a time-use survey for richer data, CT pointed out that it has its limitations, such as missing information about modes of transport.

CT also mentioned the challenge of modelling pedestrian behaviour at a detailed level, stating that it might not be feasible for a large area like London. The focus is mainly on the seven main modes of transport, and they do not run simulations for pedestrians at a detailed level.

Concerning interactivity between different modes of transport, CT noted that their model accommodates multimodal travel patterns. They track the main mode of transport used for each trip but have the capability to output all three modes used for a trip, allowing for the analysis of complex travel behaviours, particularly for sustainable travel modes.

In summary, TfL relies on comprehensive household survey data, adapts data from traditional models for AcBM, is exploring ways to incorporate in-home activities data, and considers the challenges of modelling pedestrians and multimodal travel within their model.

Policy objectives

The key focus is on pricing policies, including area pricing and peak pricing. Traditional models had limitations in addressing these pricing strategies, such as tracking individual agents and capturing complex behavioural impacts. However, the activity-based model (ABM) proved successful in addressing these challenges.

The transition from traditional models to AcBM was not without its difficulties, particularly in securing support from higher management. CT emphasized the importance of being able to demonstrate the effectiveness of the AcBM. While still using the traditional model (Motion), they highlighted the advantages of AcBM in handling specific policy questions, such as differentiated pricing during peak and off-peak hours. The AcBM provided more grounded insights into people's travel patterns, making policy decisions richer and more targeted.

CT also noted that the complexity of the model did not make it more challenging to explain to stakeholders. In fact, the individual-focused nature of AcBM made it easier for people to understand how agents plan their travel days. The model's transparency and the ability to segment the population for analysis and policy discussions contributed to its success in explaining and supporting policy decisions.

In summary, the main policy objective of TfL's AcBM was to improve pricing policies and better understand how individuals respond to them. The AcBM's ability to provide more detailed insights into individual travel plans and behaviour made it a valuable tool for supporting policy decisions and explaining them to stakeholders.

Challenges

Initially, the AcBM was seen as a research and exploratory tool, and there was no immediate funding available to build it. However, they had the advantage of already possessing the necessary data, including network data and household data, which allowed them to initiate the development.

The development process was described as slow and creative. It involved going back to the drawing board multiple times to refine the framework, incorporate the right variables to answer policy questions, and ensure the model's effectiveness. Unlike traditional models, the AcBM presented unique challenges that required a creative and iterative approach.

Another challenge mentioned was the need for the right knowledge and expertise within the organization. TfL had to invest in training and building a core group of people who could understand AcBMs and data science. This was a significant undertaking, but over time, they managed to assemble a team with the required knowledge and skills.

CT's personal journey included academic experience, publishing papers in the field, and learning through practical model development. Building an AcBM required a strong foundation in traditional models, as many challenges were similar. The iterative process of developing the model and refining it with real-world policy questions allowed them to learn and improve gradually.

Overall, the challenges included securing initial funding, developing the model iteratively, and building the right team with the necessary knowledge and skills. The process was both a creative and educational journey, resulting in the successful development of the AcBM at TfL.

Moving forward

CT emphasized the importance of demonstrating that AcBM can handle the same policy questions as traditional models while also addressing the policy questions that traditional models are not designed to handle.

CT suggested that SIVMO could initially keep both the trip-based and tour-based models alongside the AcBM to facilitate a smooth transition. By having both models available, they could compare the outputs for similar policies, assuring stakeholders that transitioning to AcBM wouldn't result in significant losses. This approach allows for a gradual shift towards AcBM without abrupt changes.

However, CT also acknowledged that maintaining two models might be resource-intensive and not necessarily straightforward. Resources, including funding and expertise, are important for successfully implementing AcBM. Depending on the available resources, SIVMO should strategically balance their focus between running existing projects on traditional models and investing in the development of the new AcBM.

CT's advice highlights the need for a thoughtful and convincing approach when introducing AcBM and stresses the importance of demonstrating its capabilities for a seamless transition.

5.12 Filip Vang

Filip Vang is Transport model specialist at the Municipality of Copenhagen.

COMPASS model overview

Model components

FV opens the discussion by delineating the COMPASS model, which comprises a route choice model and a transport demand model. The assignment model aligns with other Danish models but is differentiated by its demand component. Walking routes in this model are basic, focusing solely on pedestrian path types, while cycling routes incorporate environmental attributes, such as proximity to industrial areas or green spaces, affecting route desirability. Car routes, however, incorporate a dynamic assignment model that details congestion by the minute, rather than in broader time spans, offering a finer resolution of traffic flow around Copenhagen. Compass has both types of assignment. Both a detailed and a more general, where the day is only divided into 10 time spans.

Transport demand model

The heart of the COMPASS model is the transport demand model, which generates a synthetic population on a household level to reflect interdependent decision-making. This model includes various sub-models that simulate decisions ranging from work location to vehicle ownership and trip timing. The DaySim, an activity scheduler, outputs detailed diaries of population movements, underpinning the model's utility in planning.

Dynamic simulation

A significant feature of the model is its dynamic route choice simulation for the entire Greater Copenhagen area. Despite the detailed minutely congestion modelling, this dynamic aspect is used only as the final step in simulations due to convergence issues with the supplier's technology.

Inclusions and exclusions

Regarding vehicle occupancy, COMPASS differentiates between solo drivers and those with passengers by assigning different values of time. However, the model does not detail the number of passengers, but rather whether passengers are present. Public transport is extensively modelled, encompassing a wide variety of services with distinct value-of-time assessments. Notably, bike-sharing is not included, and the treatment of taxis within the model remains ambiguous.

Agent-based modelling

FV clarifies that in COMPASS, the concept of agent-based modelling is applied to individuals, with each person's transport needs driven by their activity requirements. Transport is considered a cost incurred to enable valued activities. This perspective integrates the movement of individuals (agents) with the purposes of their journeys, reflecting the dual nature of traffic and household activity modelling in COMPASS.

Freight modelling

The freight component is integrated into COMPASS but operates as a constant to simulate congestion, without the intricate need-calculation applied to individual activities. This approach reflects actual congestion influences while acknowledging the different modelling requirements for goods transport versus passenger movement.

Origins of the model
FV addresses that the origin of COMPASS probably stems from an inspiration drawn by politicians during a visit to Singapore. They envisaged a dynamic, visually captivating control room, but ended up with a strategic, mesoscopic model — a tool different from what they anticipated but has proven useful. This model, initially conceived to mimic bustling urban control centres, now serves more grounded, strategic purposes.

Application of COMPASS for policy initiatives

Model utilisation for policy initiatives
COMPASS is currently utilised for various infrastructure projects, with the "Green Boulevard" being a significant initiative. This project aims to transform a major thoroughfare into a subterranean road, topped by a pedestrian and cyclist-friendly park. However, the model does not extend its utility to more nuanced areas like Mobility as a Service (MaaS) or micro-mobility. Though some elements, such as taxis or skateboards, are accounted for similarly to bicycles, complex questions about new forms of urban mobility are beyond its scope.

Parking policies
FV notes that while parking facilities in Copenhagen are incorporated at the zone level, the model does not accurately reflect the real-world challenge of finding parking at home. Despite this limitation, it includes on-street parking and car parks, capturing a significant part of urban parking dynamics, albeit with acknowledged deficiencies, similar to those faced in the Netherlands.

Challenges and precision in applications
FV discusses the challenges faced during the model's implementation, particularly when expectations for precision did not align with its actual capabilities. Although it offers detailed simulations, discrepancies between the model's predictions and real-world traffic data have led to difficulties in in-house use. The model excels in standard infrastructure planning but falters when addressing complex policy changes, like those aimed at reducing CO_2 emissions through simplistic calculations.

Data in COMPASS

Data foundations
The conversation pivots towards the foundational data required for the COMPASS model. A household person trip survey forms the core data set, encompassing 10,000 annual respondents regarding transportation behaviour, with a focus on ensuring 1,000 of those respondents are from local citizens for enhanced accuracy within the municipal area. This is complemented by specialized studies, particularly those since the year 2000, that delve into household travel behaviours to gather the nuanced data necessary for household-level estimations.

Data utilization
There is an emphasis on the static nature of data within COMPASS, with updates only occurring through manual importation. Key data sources include a smart card system akin to London's Oyster card, which provides a substantial portion of public transport

data, and a detailed Journey Planner dataset for scheduling. While GPS data from buses, cars, or bicycles is not currently harnessed, its potential to refine the model is recognized.

Parking data challenges
The discourse highlights the intricate process of annually collecting parking data, which includes documenting various parking restrictions but acknowledges gaps such as private and workplace parking provisions. This data is essential, yet its collection poses challenges and requires meticulous processing.

Processing and costs
Discussing the extensive nature of data processing for model updates, which is scheduled biennially or annually, the conversation reveals the reliance on a SQL database and a focus on automation to minimize errors and labour intensity. There is a fortunate absence of direct costs for data, with public transport information being freely available, though there are considerable expenditures for software licensing.

Privacy considerations
Privacy and ethical issues are briefly mentioned, with assurances that any potential concerns have been mitigated by using aggregated data and synthetic populations in the model, thus sidestepping individual privacy issues. This ensures compliance with legal and ethical standards while maintaining data efficacy.

Internal and external collaboration

Inter-organizational collaboration
The discussion elucidates on the collaboration aspect of the modelling team with external entities. The cooperation with other organizations such as statistical offices or other departments appears to be minimal. This is primarily because of the municipality's size and its capability to internally access sensitive statistical data through colleagues who possess 'scientist access'. The exchange of information is tightly controlled, with data only being shared once it's aggregated to a broader level, specifically to the micro-zone level, ensuring individual data points remain confidential.

External engagements
There is a slight degree of cooperation with the Road Directory, which is referenced in specific scenarios such as forecasting traffic expectations for the airport for a future year like 2035. This interaction seems to be limited to information needs rather than a continuous partnership. Project managers from both teams talk regularly. Both parties want to collaborate more in the future.

International collaboration
When it comes to international collaboration, the discussion clearly indicates an absence of engagement with counterparts in Sweden or London. This suggests a focus on localized data handling and model development within the confines of the municipality's jurisdiction without extending to a broader international framework.

Modelling issues

Software framework

The COMPASS model is primarily built on the Rapidis software framework (Traffic Analyst), which manages scenario controls and calculations. It integrates route choice models from Rapidis, demand modelling from open-source software, and custom coding in languages such as Python and C++. The fusion of proprietary and open-source tools is a hallmark of the model's technical infrastructure.

ICT infrastructure

On the technical side, FV mentions that their servers are operated by the IT department and are located in Denmark. FV confirms that they do not utilize cloud servers, which could potentially offer faster processing times and mitigate issues of hardware becoming outdated. The use of their own servers also implies a limit on computational resources, which affects the overall speed and efficiency of running such extensive models.

Activity modelling

A critical component of the COMPASS model is a sub-model termed 'Primary Family Priority Time'. This sub-model reflects periods during the day when family members generally engage with each other, such as dinner, and cannot undertake other activities. This element showcases the model's attempts to replicate familial interactions and domestic routines.

Work and E-activities

The dialogue touches upon the inclusion of remote work within COMPASS. While work from home is incorporated, other non-working online activities like e-shopping or e-learning are not directly accounted for. However, the growing relevance of such virtual activities and their potential implications for the accuracy of activity-based models is acknowledged.

COMPASS and cross-border integration

The conversation shifts the geographical scope of COMPASS. There's an acknowledgment that although the model's current reach is limited to Denmark, logically it should encompass parts of Sweden such as Malmö due to the traffic interactions with Copenhagen. The current workaround to include Swedish influence is through the port zone traffic, which accounts for movements from outside the region into it, with a focus on different traffic types including through-going and incoming/outgoing traffic.

Modelling techniques (pivot-point method)

Further exploration reveals that current models employ constants for predicting traffic, which remain unchanged during forecast updates unless modified in custom future scenarios. Methods like the pivot-point technique are part of COMPASS, used after demand modelling and before route choice to calculate growth factors, which are then applied to a base matrix.

Methodological concerns

The base matrix, an aggregation of transport demand, is raised to a higher zone level for pivot-pointing. For future projections, it remains at this aggregate level during route choice modelling. Although pivot-point techniques have benefits, there are issues such as variability in output, where repeated runs of the same model yield differing results. This inconsistency raises concerns about the reliability of interpretations made from the model, particularly when small variations can significantly impact the pivot-point calculations.

Some further information

The zone level in the demand model is the most detailed, with 10000 zones in the model. The route choice zones are more aggregated with 4000 zones in the area, while the pivot point-zones are the most aggregated with only 1000 zones. So, even though the pivot-point weight factor is calculated at a more aggregated level, the pivot pointed traffic is distributed through a more detailed zone system.

Reproducibility and stochasticity

FV discusses the challenges of reproducibility in activity-based modelling due to stochastic elements. While some components, like the population synthesis, provide consistent results, other aspects of the transport demand model do not, leading to considerable variation. This variation was evident in simulations, testing the impact of reduced speed limits on public transport usage, where the outcomes were not as expected. Addressing these stochastic issues remains a challenge, and it may be more feasible to focus on understanding significance levels and interpreting results within the context of daily variations that occur in real-world traffic patterns.

Communication on results

Communicating variability in results

The challenge discussed here revolves around conveying the results of the COMPASS model to policymakers who may not be receptive to the concept of variation within the data. The primary concern is establishing trust in the model's outcomes, especially when results defy intuitive expectations, such as an increase in car traffic after the closure of a bridge. FV acknowledges that communication is as significant a problem as modelling itself and remains an unresolved issue.

Trust and Interpretation

To bridge the gap between the complex model results and policy formulation, FV emphasizes honesty in communication, especially when relaying information to colleagues who are responsible for interpreting the data to the policymakers. This approach includes being upfront about the limits of confidence in certain results, sometimes opting not to report findings they deem not robust enough or not sufficiently reflective of the intended scenarios.

Visualization expectations

Despite the challenges in model variability, there is still an expectation for visual representations such as graphs, tables, and maps, which can be problematic if unexplainable changes occur. This is contrasted with practices in the Netherlands, where strict policies and procedures ensure full disclosure and the ability for local entities to review and understand the modelling processes.

Pros and cons of the activity-based approach

Model detail

The conversation begins by comparing the benefits of activity-based models against more traditional trip- or tour-based models. The primary advantage of an activity-based model is its detailed results and the accuracy with which it mimics real-life movements of individuals. FV notes that while the decisions made by each agent in the model are more precise, many questions posed by the municipality are basic enough that they could be addressed by simpler models, suggesting that sometimes the complexity of an activity-based model may not be necessary.

Simplicity vs. complexity
The discussion pivots to the necessity of complex models for answering straightforward questions. FV muses that for most queries, a less complicated trip- or tour-based model might suffice. The inherent stochastic nature of the simulation in activity-based models generates a certain degree of noise, potentially complicating the interpretation of results when a simpler model could offer clearer answers.

Computation time
A significant 'con' that FV points out is the extensive computation time required by activity-based models. Running the complete model can take up to two weeks (14 days), which is a considerable duration, especially when compared to the needs of the municipality, like assessing the impact of temporary road closures for maintenance. Such a long computation period is not practical for timely decision-making.

Decision quality
FV addresses the question of whether the complexity of the COMPASS model leads to superior decisions. He finds the question challenging because prior to COMPASS, there was no model in place at all. He suggests that having any model is better than having none, implying that the very presence of a structured approach to decision-making is beneficial.

Complexity vs. utility
FV seems to indicate that it isn't the complexity of the model that drives better decisions but the accessibility and internal understanding of the model (results). The key advantage seems to be the in-house expertise that allows for flexibility and a deeper comprehension of the results, which enables them to guide their colleagues more effectively. This in-house capability reduces the need for external consultancy, thereby reducing extra costs and potentially leading to more informed decisions due to the ready availability of knowledgeable staff.

In-house advantage
FV believes that the in-house management of the COMPASS model is more advantageous, as it allows for a greater degree of flexibility and a more hands-on approach to interpreting the results. The implication is that having control over the model and its analysts within the municipality leads to a better understanding and potentially improved policymaking, rather than the complexity of the model itself being the decisive factor.

5.13 Tim Heirman

Tim Heirman is engineer at the Vlaamse Overheid

Model use in Flanders

TH explains that the Flemish Government uses a set of strategic traffic models. This includes a main model integrating demand, supply, and network modelling. The regional traffic models, focusing on specific areas in Flanders, derive from this main model. These models borrow their transportation demand from the main model and primarily concentrate on network aspects. This technique is similar to that of Rijkswaterstaat and the Province of North Brabant.

Four-step model and tour generation

The methodology of the model follows the structure of a classic four-step model, determining tour frequency, motives, times of the day, destinations, and modes of transportation successively. The model also adds supplementary tours for a more detailed insight into secondary destinations. Based on these steps, the main model generates a list of tours, which are then further calculated and optimized by the network model.

Agent-based approach

The model is described as 'agent-based' because it assumes decision-making at the individual level. It lacks a complete 'activity-based' character as it does not compile a complete daily program for each agent. An agent, as defined by TH, is characterized by personal attributes such as gender, age, and occupation, and household features. Although households provide important attributes for agents, they are not considered independent agents within the model. The network model is not 'agent-based' but has a static assignment and works with a traditional OD matrix to calculate generic costs.

Software

Visum is used for the network model, while the transportation demand model runs on self-developed software written in Visual Basic. The demand model is compatible with Visum through the exchange of HB matrices and cost calculations, maintaining a relatively simple interface between the two models.

Use of the model in policy issues

Policy objectives of the model TH indicates that the model is primarily designed for policy-oriented objectives. The model is mainly deployed within the permit process that large infrastructure projects must undergo, with a crucial part being the Environmental Impact Assessment (EIA). The quantitative substantiation relies on model results from the Regional Traffic Models. In recent years, it has also been used in the development of the Regional Mobility Plans that frame the mobility policy of the 15 Transport Regions. An important objective is achieving a better modal split. The agent-based structure of the Strategic Personal Models provides a better explanatory framework and confidence in the results for both applications. Initial expectations seem partially fulfilled, but TH notes that there is still room for improvement. While the model is praised for its advanced nature, most questions are primarily focused on the development or adaptation of infrastructure and its consequences, expressed in, for example, vehicle kilometres. Although the model can provide better support for questions, TH acknowledges that many steps need to be taken to fully utilize the model optimally. This requires effort from partners and departments to look beyond the current uses of the model.

Policy use and limitations
The discussion continues on the potential of the model for issues related to justice in transportation, such as 'equity' and 'accessibility.' TH notes that these types of policy-relevant questions are rarely asked, although the model could provide insights into these themes. The need to further develop the model is emphasized, but at the same time, there is a practical limitation due to the abundance of existing questions for which the model is used. These practical challenges result in the model being less utilised for such in-depth policy questions.

Model use at different government levels
Another expert is mentioned, suggesting that activity-based models are more suitable at the regional or urban level rather than the national level. TH agrees with this and points to the level of detail as a crucial factor. Despite the model being agent-based, the large zones it operates with remain a limiting factor in data granularity. It is suggested that a Flemish model could act as a tool for detailed local traffic models.

Technical and political considerations
The distribution of the 5,000 zones in the model appears not to be a political choice but rather a consequence of limitations in computing capacity. The zones are chosen based on the numbers of residents/workplaces/students and a correct representation in the model.

Challenges in policy implementation
TH elaborates on the difficulties of implementing policy measures in the model. It is explained that, while the model can simulate certain infrastructure adjustments, they often involve vague concepts that need to be creatively modeled. Adapting the model to reflect policy changes such as improvements in cycling infrastructure may result in results that are not always satisfactory, even though these adjustments show an effect in the model. The challenge lies in balancing the precision of the model and the need to sometimes work with rough approximations.

Data for the model

Overview of used data
TH discusses the use and limitations of the available data for their models. Household surveys, which should provide important information, prove inadequate for model development. The most recent extensive survey dates to 2001, with a smaller version in 2011. The intention was to organize a new survey every ten years, but the pandemic disrupted these plans.

Travel behaviour research
The travel behaviour research (TBR), conducted almost annually, forms the basis for their model. The research surveys a large group of Flemish and recently also Brussels residents about their mobility behaviour. This research is considered highly relevant as it directly establishes connections between personal characteristics and travel features.

Activities and e-commuting
Specific questions about movements and e-commuting are asked in the TBR surveys, but not about other home activities. However, this would be important since the replacement of physical movements by digital alternatives is a growing trend. TH recognizes the importance of measuring this shift, and additional data on digital alternatives within an activity-based model could be interesting. This could be obtained, for example, through the survey.

Traditional data, big data, and future data sources
Although the model mainly relies on traditional datasets, TH acknowledges that not enough use is made of big data. The integration of new data sources, such as smartphone and public transport card data, is actively being considered by public transport providers, and their use for model validation is also being considered. However, due to privacy and competition sensitivity, there is still a long way to go.

There is an interest in exploring new data sources for specific purposes, such as understanding cross-border movements. This consideration considers possible biases that may creep into the model, and there is a preference for traditional counts currently considered more reliable.

Collaboration and knowledge sharing

International collaboration
TH highlights the potential of collaboration with Dutch partners such as the Province of North Brabant and Rijkswaterstaat. There is currently an InterReg project in the subsidy application phase, so its realization is not certain. The expectation is that this project will promote international collaboration, especially with the Zeeland region.

Exchange and collaboration
The discussion on collaboration extends beyond data exchange to sharing model information. TH mentions a meeting with various parties, including the Province of North Brabant, where it was suggested to expand discussions to jointly share models and knowledge. It is acknowledged that close collaboration can lead to a better understanding of common challenges.

Benefits of knowledge sharing
TH believes that collaboration and knowledge exchange can strengthen not only the involved parties but is also in the general interest. There is a proposal to share not only data but also expertise, benefiting all parties. This idea is presented as a concept that needs further development.

Model details Benelux model
TH discusses the possibility of an overarching Benelux model where the Netherlands, Belgium, and Luxembourg would function as sub-models. He mentions the existence of European models like Trimode but notes their coarseness. TH suggests that integrating the models of Flanders, Brussels, and Wallonia into a larger model could be reliable and improve the exchange of information and modelling of smaller border movements. He sees potential for such collaboration but also points out the reduced relevance of movements as the distance increases, justifying the focus on individual models.

Population synthesis
TH confirms that the Belgian population synthesis covers the entire country, and although Wallonia has less focus than Brussels, it is essential for modelling. Adding Brussels and Wallonia to the modelling also contributes to credibility in policy negotiations. It is not much extra effort once the model framework is established. He confirms that Brussels is modelled at the same level of detail as Flanders.

Study area and level of detail
Regarding the study area, TH distinguishes different zones: Flanders and Brussels as the primary study areas, followed by a first shell of about twenty kilometres in Wallonia, considered as a second study area. Beyond this zone, the level of detail decreases. He acknowledges that collaboration with Dutch regions such as Zeeland and North Brabant could further improve the level of detail.

Organizational and technical challenges
Data challenges TH discusses the organizational challenges in using the models and collecting data. He emphasizes the dependence on surveys, which are essential but also vulnerable, as illustrated by the impact of the pandemic. The representativeness of data is important to avoid bias, and he explains that they sometimes must rely on outdated data, which they try to update with more recent data. TH underscores the need for current and representative surveys to accurately model changing modes of transportation and behaviours.

Stochasticity in the model
TH confirms the presence of stochasticity in the model but not in a way that jeopardizes the reproducibility of results. The model uses Monte Carlo simulations to establish the tour file. However, the use of the model is fixed, meaning that no further Monte Carlo simulations are performed after the initial formation of the tour file. This ensures consistency in the scenarios executed.

Challenges of the model
The complexity of destination choice within the model poses a challenge, especially at the level of agent-based modelling. TH indicates that finding a balance is not feasible. Striving for equilibrium is particularly challenging at the district and zonal levels. The validation of model results with current data seems to be a concerning confrontation for TH, with the expectation that the model results will not fully align with reality.

Communication and policy choices
TH states that the emphasis on reproducible results is not as prevalent within the Flemish context as it is in the Dutch context. Reporting at higher aggregation levels is chosen to keep the complexity of the models manageable. Agent-based and local effects are then less visible. This approach makes it easier to explain results to policymakers who are less familiar with the workings of models.

Future developments
Plans for the model include an update with a new reference year and future year. Additionally, there is an intention to thoroughly revise the model, with a possible focus on an activity-based approach. The emphasis is on improving internal logic and adding more detail, such as distinguishing work patterns between different sectors and employee groups.

Technological evolution
When asked about the transition from 3G to 4G and the potential transition to 5G, and whether these changes have led to more work or higher costs, a concrete answer is not provided. TH seems to indicate that the team is still in a preparatory phase regarding the direction of the new model version.

Management and maintenance
The development and management of the Flemish government's model require a substantial amount of time and financial resources. Although TH indicates that the technical aspects of the project are not particularly complex, building from the ground up is time-consuming and requires a lot of development work. TH is hesitant to provide detailed technical information and suggests that he may not be the most appropriate person to delve deeply into these issues.

5.14 Mark Bradley

Mark Bradley is Partner at Blue Door Strategy and Research

Context and definitions

Defining activity-based and agent-based modelling

In the discussion, MB delineated the nuances between activity-based and agent-based modelling. He described agent-based modelling as an approach that completely disaggregates data, focusing on modelling individuals over time. He emphasised the flexibility of this method, allowing the scheduling of significant daily activities while accommodating additional tasks around them, even if not chronologically. Activity-based modelling, according to MB, was a subject of contention in academic circles. Some experts, like Eric Miller, argued for predicting all activities beforehand, while others, including MB, advocated an iterative approach. In this iterative process, essential activities like work or school were scheduled first, and the remaining activities were planned based on available time. The objective of activity-based models was to study daily activities and their intricate relationships, focusing on interactions between various tours, thereby differentiating them from conventional tour-based models.

Agents in modelling: persons and vehicles

The conversation delved into the concept of agents within these models. Agents, in this context, primarily referred to individuals, sometimes within households. MB emphasised that agents could also represent vehicles, especially in models where scheduling vehicles over time was a crucial component. However, he noted that these models typically limited interactions to the household level. The distinction between demand modelling and assignment was highlighted, underlining the critical role of agents in transportation demand modelling. Whether as individuals or within households, agents formed the core of modelling scenarios, interacting to shape the overall model dynamics.

Assignment methods and model development

The discussion transitioned into assignment methods used in practical modelling scenarios. Although dynamic traffic assignment was acknowledged, MB pointed out that most practical models in the US predominantly relied on static assignment methods. European models, particularly exemplified by those in Copenhagen, were cited as utilising dynamic assignment techniques, showcasing the diversity in global modelling practices. The conversation then shifted towards software options and the complexities associated with them. Open-source solutions like ActivitySim were discussed as attempts to democratise access to modelling without necessitating extensive coding knowledge. MB highlighted the challenges faced by consultants and companies, focusing on the financial implications of acquiring software and the time-intensive learning curve required for effective usage and modification of code. The conversation provided valuable insights into the ongoing debate concerning tailored models versus commercial software, drawing on the Dutch national model as a pertinent example. The discussion underscored the intricate technical elements and practical challenges faced in the development and application of these advanced modelling techniques.

Data

Necessary data for activity-based models

In this section, MB and JK discussed the essential data requirements for activity and agent-based models. MB emphasised that the necessary data for these models was akin to what was needed for trip-based models, including networks, census data on the population, and access to data from surveys. He mentioned the American Community Survey, a significant data source in the US, which provided data for a large sample of the population, used for synthetic populations in activity-based models. The conversation briefly touched on the relevance of adapting surveys to account for changes in activities like e-commuting and e-shopping, especially post-pandemic.

Response rates and data collection methods

The discussion delved into data collection methods and response rates. MB highlighted their use of smartphone-based app surveys, which allowed respondents to record their activities over a week. While this method generated more data per person, it didn't necessarily increase the number of participating households. The app automatically registered travel based on dwell times, prompting users to answer questions about each trip, such as destination and mode of travel. The conversation addressed biases in traditional surveys, with some respondents reporting fewer trips or omitting certain stops, a challenge mitigated by smartphone-based surveys.

big data and model calibration

The discussion transitioned into big data applications in activity-based and agent-based models. MB noted that big data, combined with surveys, was used for calibration and validation, particularly for Origin-Destination matrices. He shared challenges faced in using location-based services data, such as missing trips and poor data quality, exacerbated by changing privacy agreements. MB mentioned companies like Streetlight, which gathered data for model calibration but faced challenges due to data quality. He also discussed the Replica project, owned by Google's Alphabet, which claimed to estimate activity patterns akin to activity-based models using extensive data. However, Replica's methods remained opaque, raising concerns about transparency, especially in the context of governmental use. JK highlighted the transparency standards in the Netherlands, emphasising that such opacity would not be acceptable in their modelling practices. The conversation underscored the complexities and challenges in incorporating big data into nuanced and transparent modelling frameworks.

Public transit in activity-based models

In this section, MB and JK discuss the integration of public transit data into activity-based models, focusing on the challenges faced in the United States. MB points out that while transit plays a significant role in Europe, its impact is relatively lower in the US, yet efforts spent on modelling it are substantial. A noteworthy trend is the increasing focus on cycling, driven by government initiatives to alleviate traffic congestion, especially with the rise of e-bikes. This policy interest has led to extensive research on cycling patterns and their potential impact on transportation.

In the US, activity-based models often employ dual or even triple zone systems to accommodate different modes of transport effectively. Traditional larger zones are used for car traffic, encompassing most car trips and transit routes. Additionally, micro zones, roughly the size of a city block, are utilised for modelling shorter trips, walking, biking, and accessing transit points. To further refine transit-related data, a third zone system, known as transit-stop areas or access points, is employed. These zones encompass stops, groups of stops, or stations close to each other. The simulation software handles the access and egress portions of transit routes, finding the optimal path via these access points. However, this approach necessitates meticulous data preparation, constituting an additional workload for researchers.

Regarding transit data sources, MB mentions GTFS (General Transit Feed Specification), a widely used format providing free access to public transit data. Despite its availability, integrating this data into activity-based models requires creating and maintaining an additional network, adding complexity to the modelling process. MB highlights the importance of having a comprehensive streets network, like the one provided by OpenStreetMap, to account for geographical features such as rivers and bridges, important for accurate route planning and overcoming obstacles in urban areas.

Methods

Navigating stochasticity and model complexity in activity-based modelling

In this section, the discussion discusses the intricacies of stochasticity within activity-based models, particularly addressing concerns related to the reproducibility of results, a critical aspect in the Dutch context. JK emphasises the Dutch emphasis on ensuring stable outcomes, which sparks a conversation about the challenges of achieving consistency, especially in smaller regions. Historically, sub-sampling of the population was employed in these cases due to limited computational capabilities. However, with the advancement in software speed and computational power, a shift towards super-sampling has occurred. This method involves simulating multiple days for everyone, creating a larger dataset that tends towards an average due to statistical principles. MB highlights the caution necessary when interpreting highly detailed results, pointing out the inherent variability as analyses become more granular.

The conversation then pivots towards innovative techniques designed to manage stochasticity, specifically semi-stochastic procedures like the Halton sequence, which are being experimented with in the Netherlands to ensure consistent outcomes. However, MB expresses his unfamiliarity with these techniques and mentions the gap between academic exploration and practical implementation. He notes the complexities introduced by these methods, making it challenging for practitioners to understand the nuanced changes in the model's outcomes. Despite this, MB shares insights into the use of distributed value of time, where random distributions are drawn for each agent based on factors such as purpose and income, showcasing the nuanced approach to incorporating stochastic elements within the model.

Model size

Regarding model size, MB states that activity-based models for regions typically cater to populations ranging from one to three million people. While statewide models exist in the US, a national model predicting local travel is non-existent due to the immense complexity involved. MB emphasises the challenges of network complexity, making practical application exceedingly difficult on a national scale. Instead, regional models are the norm, catering to populations ranging from half a million to five million people. Even within regions, sub-models are created to meet specific requirements of counties or cities. These localised sub-models may undergo super-sampling techniques to maintain consistency, showcasing the nuanced strategies employed to manage complexity in practical activity-based modelling applications.

Navigating the transition to activity-based models

In this section, JK seeks advice from MB on transitioning from trip-based or tour-based models to activity-based models. MB's counsel underscores the importance of a gradual approach, advising against attempting overly complex models all at once. Drawing from an example in Copenhagen, where an intricate model system proved overwhelming due to its complexity, MB suggests starting with simpler existing model structures. The modularity of platforms like the activity sim platform allows for the gradual integration of new elements, providing flexibility in adapting to evolving data needs. He stresses the significance of data quality and checking, important factors that often determine the success of such transitions.

The conversation then touches upon the timeframes involved in this transition. MB explains that while data development consumes substantial time, the switch to existing platforms usually takes one to two years with the assistance of consultants. This prompts a discussion about training personnel and the involvement of government agencies. MB highlights the varying levels of involvement among agencies, with some preferring hands-on engagement in model development, while others opt for external expertise due to limited resources. The disparities in funding and job benefits among government agencies in the US impact the recruitment and retention of skilled staff, further shaping the approach to implementing these models.

Model application

JK asks about MB's personal experiences in applying these models. While MB does not directly engage in applications, he collaborates with colleagues who do. He emphasises a shift in focus from development to application due to the availability of existing platforms. MB mentions the challenges faced in calibration and validation, indicating that sometimes issues attributed to activity-based models might stem from shortcomings in other related models, such as freight or traffic models. The discussion briefly touches on freight models, indicating ongoing efforts to develop tour-based freight models, highlighting the complexities faced in this specific domain.

5.15 Erik de Romph

Erik de Romph is Leading Professional Traffic Forecasting and Simulation at Royal Haskoning DHV.

General understanding of activity-based models

Definition of activity-based models

ER emphasises that activity-based models assume activities as the starting point for the movements people make. They try to explain people's movements based on the activities they undertake. Importantly, the decisions people make regarding activities and the associated movements depend heavily on personal characteristics and the conditions they encounter along the way. Activity-based models focus on individuals and take into account concepts such as tours along activities.

Disaggregated approach and 'agents'

ER confirms that activity-based models consider different modalities, motives and activities. They model what happens on a per-individual basis and approach people's movements in a highly disaggregated way. While they are often referred to as "agent-based models" because of their focus on individual decision-making, ER notes that, strictly speaking, they are not true agent-based models. This is because true agent-based models require interactions between the agents in the model, which is rare in activity-based models.

Interaction within households

ER acknowledges that there are dependencies between individuals within households, but emphasises that in most models, the choices of individuals within the household are still independent. While the model may ultimately average the correct outcome for car choice in a household, it does not consider what other household members have decided during the choice process, unlike true agent-based models.

Dynamic assignment and simulation models

The talk addresses the idea that dynamic assignmet models, such as microsimulation models, can be considered agent-based models because of the interaction between agents over time. ER agrees but notes that such models can be complex and unstable, with a lot of stochasticity. Although they are the ultimate individual model, he has never applied them practically because of their complexity and uncontrollability.

Terminology: activity-based models or agent-based models?

ER prefers the term "activity-based model" and suggests avoiding the term "agent-based model". He stresses that this is the purest name based on the definitions of the models.

Supply and demand models

The interviewer asks ER to clarify his understanding of demand and supply models. JK explains that as far as he is concerned, demand models deal with who, where, how and when people travel, while supply models focus on the infrastructure, modes and organisation of the transport system. ER sees route choice as an aspect of demand models, while the settlement of these choices on infrastructure is dealt with in supply models.

Route selection within supply and demand models
ER stresses that route selection is usually handled in the supply model and not in the demand model. However, he admits that in some cases a route choice model can be considered as part of the demand model, especially in an iterative process. Nevertheless, he points out that in common models, separate traffic demand modelling is always done to assign the OD matrix or HB matrix to the network and generate a loaded network.

Interaction between supply and demand
ER stresses the importance of interaction between demand and supply models. He notes that sometimes, to make calculations simpler and faster, the interaction is omitted, but in realistic models there is always some form of interaction between the two.

Output of demand models
ER indicates that demand model output is often aggregated to HB matrices for practical assignment. This is done in practice because assignment algorithms need this type of matrix as input. Although demand models can be complex, they are often reduced to more simple terminology and output formats to make it understandable to customers.

Data for activity-based models

Suitability of data sources
On the suitability of existing data sources in the Netherlands, ER notes that activity-based models use OVIN or ODIN as data sources for estimating the parameters of these models, but that there is room for improvement. He stresses that the size of the data sources, especially the number of people and sample data, is thin. This can be a limitation in more detailed modelling with activity-based models, as individuals are included in the model who are not included in the sample.

Challenges in improving data sources
ER discusses the possibility of stacking OVINs, but considers this a poor solution, especially because of the variability of behaviour in this day and age, caused in part by technological developments and events such as epidemics. He stresses the importance of increasing sample sizes to account for different behavioural patterns.

Improvements in data sources
Asked what he would improve if it were up to him, ER stresses that the survey questions and data collection are good in themselves, but the sample size needs to be increased. He explains that behaviour can vary locally (Friesland versus Limburg). There is a need for high repsons in the surveys to improve the representativeness of the data.

Inclusion of home working and home activities
ER is asked whether activities that take place at home, such as working from home, should be included in the data sources. He confirms that this is important and suggests that working from home should be recorded as an activity. This may include recording activities such as home shopping and online business calls.

Complexity of modelling process
ER acknowledges that how far you want to go in including home activities is an important issue. He points to the challenges of modelling behaviour that takes place outside the home, and how technological developments can rapidly change this behaviour. Such developments are still a major challenge for modellers.

Switching to electronic data
The question is whether the current use of diaries (such as OVIN) as a data source is still viable and whether it makes sense to switch to electronic data collection via apps. ER believes that this switch does need to be made, as it is more efficient and effective. He notes that CBS is already collecting data electronically and is confident that they will ensure the representativeness of the data even if some people are not surveyed.

Expansion of data sources
ER reiterates that an expansion of the sample size is desirable. He suggests that people should be followed over a longer period to get a better picture of their mobility behaviour. He points out that the number of trips per person may be higher than what is recorded in OVIN, mainly because of the small sample size and people's tendency not to record short trips to supermarkets, for example.

Use of apps for data collection
ER endorses the use of apps as a valuable addition to data collection. He points out that apps can often collect missing data (such as short trips), and can generate a significant number of observations. However, he stresses that the representativeness of the data does need to be monitored.

Regional differences in mobility behaviour
ER responds to a question about regional differences in mobility behaviour, particularly in Limburg. He notes that behaviour is not the same everywhere, even if specific characteristics are similar. In Limburg, for example, people drive cars significantly more than in other parts of the country, which may be due to the hilly environment and differences in distance distribution. He stresses that regional differences can affect the usability of OVIN data and should be addressed in the models.

Use of big data and app data
ER highlights the potential of different data sources, especially ov-chip card data and data from TomTom. He sees these as valuable sources for validating and improving basic matrices for transport models. However, he notes that it is difficult to extract individual behaviour from these data as they contain mainly quantitative information and do not relate to specific individuals. He cites the use of apps as promising but notes that it is still in its early stages.

Challenges in obtaining detailed data
ER points out the need for detailed data on the input side of activity-based models, such as age, income, and car ownership of individuals. He stresses that it is not trivial to access this detailed information and that assumptions often must be made when generating synthetic population data. He mentions the challenges in obtaining zone-based data (model zones) and explains that such information is often not available at the desired level of detail.

About Open Street Map (OSM) and income distribution
JK discusses an example where he used OSM data to perform a population synthesis. He mentions that this succeeded because they could access WOZ (property tax) values in part to derive a rough income distribution by zone. This highlights the importance of detailed data when generating synthetic populations. ER concludes that while it would be ideal to have access to a dataset with such information, this would likely require some effort on the part of agencies such as CBS to compile such data.

Privacy and ethics in small-scale data
ER stresses the importance of privacy and ethics when using small-scale data. He warns that with too small numbers of people in a zone, privacy risks arise and there are rules on how to deal with this. Privacy concerns can lead to data being omitted. He points out that using OSM data and CBS data, privacy can be maintained while generating detailed data.

Consortium of municipalities and data initiatives
ER discusses the usefulness of partnerships, where several municipalities work together on data initiatives. He stresses that such consortia, especially in terms of data, can be more efficient than each individual municipality. This allows governments to pool time and resources to collect and process detailed data.

Organisational challenges

Challenges in developing and applying activity-based models
ER discusses the challenges in developing and applying activity-based models. He emphasises that besides technical challenges, there are also organisational obstacles. ER notes that the number of experts in modelling seems to be decreasing in the Netherlands, and the knowledge among clients is also decreasing. Moving to activity-based models requires a specialised group of experts, which is currently even smaller.

Solutions to the shortage of experts
ER indicates that the shortage of experts in this field starts at universities, where the traffic modelling curriculum is being reduced. He notes that finding qualified staff is a challenge, as young professionals are often trained with other focus areas such as autonomous vehicles. ER suggests that universities such as TU Delft should put more effort into traffic modelling, including activity-based models, to train future experts.

National versus international approach
ER stresses the Netherlands should consider cooperating at the national level or through a broader international approach. He points to developments in other countries, such as the development of EMME Agent, which he believes are more advanced than the Netherlands. He suggests that software and model development may need to be more the responsibility of the government, as the business model of commercial software companies is under pressure.

Open source and collaboration
ER discusses the idea of open-source initiatives such as ActivitySim and MATSim. He suggests that such initiatives should be developed in an open-source format with the involvement of government parties as stakeholders to ensure that the knowledge and software remain public. He also encourages cooperation with foreign governments to

promote the development of basic knowledge. Collaboration at national and international levels can enhance both development and impact on the sector.

Content challenges

Content challenges in developing activity-based models
ER highlights the content challenges in developing activity-based models. He points out that building such models requires significantly more expertise and time compared to traditional four-step models. An important aspect is the complexity of the sequence of sub-models that make up an activity-based model.

Different approaches to building activity-based models
ER discusses different approaches to developing activity-based models. It is possible to develop everything at once, as in Copenhagen, or to do it incrementally. However, he stresses that the complexity of the sub-models makes getting the model right considerably difficult, and that running tests at the end of the process can cause problems.

Stochasticity and choices
ER points out the challenge of stochasticity in activity-based models. When determining the activities of individuals, numerous possible combinations arise, and individuals have to choose only one. This leads to a sense of randomness. ER indicates that this is one of the reasons why he is cautious about activity-based models. He finds it difficult to explain why only one of many possible activities is chosen, and this aspect of random choices deters him from further application of these models. However, progress has been made in this area and some experts point out that this is no longer really a problem.

Population synthesis as a no-regret step for model development
ER stresses that population synthesis is a so-called "no-regret" step for model development, even if one does not want to go straight to activity-based models. He explains that this step is useful for aggregated tour-based models, including the NRM and LMS. The complexity depends on which features you include and emphasises that not all features are relevant to travel behaviour. ER points out that some characteristics, such as gender, may not be necessary to model explicitly, and modellers can focus on relevant characteristics.

Collaboration

Need for cooperation and knowledge mobilisation
ER discusses the challenge of mobilising knowledge in the Netherlands to develop activity-based models. He suggests that the ideal approach would be to bring consultants and knowledge institutions together to work jointly on the model, despite the business and competitive aspects. He points to the existing success of partnerships such as Basgoed, where both consultants and software agencies work together. He stresses that such a partnership should include not only market players but also knowledge institutes such as universities to pool specific knowledge and give direction to model development.

Challenges and solutions for knowledge mobilisation
ER acknowledges that there are challenges in setting up such collaborative linkages, such as keeping the playing field open and involving knowledge institutes. JK

emphasises that such collaborative partnerships enable knowledge sharing, knowledge pooling and model development direction. JK notes that individual parties apply based on knowledge and experience and are selected to participate in projects, resulting in a community that develops Basgoed and shares knowledge. ER is optimistic that there are opportunities for involvement in such collaborations, ER also expresses concerns about the emergence of monopolies and that it becomes very difficult to join an 'exclusive' club of experts over time.

The role of SIVMO

ER stresses the importance of cooperation between different parties, including government parties, market parties and knowledge institutions. He points out that it is better if these parties work together instead of client-contractor situations, as this promotes knowledge sharing. He mentions the role of the organisation SIVMO and suggests that SIVMO can play a central role in such collaborations.

5.16 Cinzia Cirillo

Cinzia Cirillo is Professor at the University of Maryland, Director of TIER 1 USDOT Center on Multi-Modal Mobility and Interim Director of the Maryland Transportation Institute.

Context and definitions

Challenges and progress in activity-based models
In this discussion between CC and JK, CC provides valuable insights into the state of activity-based modelling, particularly focusing on her experiences with ActivitySim and MatSim. She acknowledges that while ActivitySim, implemented in Python, simplifies the modelling process, it poses challenges for smaller organizations lacking Python expertise. Moreover, ActivitySim only covers trip matrices, necessitating external tools for assignment tasks. CC then discusses her work on agent-based models, combining MatSim with a four-step model and land use integration. Although this approach allows flexibility and modularity, it demands expertise in Java, limiting its accessibility due to coding constraints. Despite these challenges, CC emphasises the importance of agent-based models in enabling detailed geographical analysis by working with individual agents rather than traditional zones.

JK highlights the lag in activity-based modelling in Europe, citing few prominent models in cities like London, Copenhagen, and Switzerland. CC's work in the Middle East and her observations indicate that large-scale implementation of activity-based models faces difficulties, especially in regions lacking local consultants familiar with the area. When discussing agent-based models, CC clarifies that in her approach, the model doesn't simulate activity choice but focuses on population synthesis and trip generation. MatSim handles the planning, allowing initial plans from an activity-based model to be integrated into MatSim's simulation framework. This method differs from a full-fledged activity-based model, resembling Sweden's approach, where population synthesis provides the groundwork for agents' trips without detailed activity choice modelling.

Regarding population synthesis, CC discusses the prevalent use of Iterative Proportional Fitting (IPF) but notes its limitations in handling numerous dimensions. She highlights the evolution towards machine learning methods, specifically Bayesian networks, offering improved accuracy and scalability, allowing for simulation with more dimensions. Despite the computational challenges, CC's work demonstrates progress in overcoming these obstacles, paving the way for more complex and nuanced activity-based modelling approaches.

Data

Essential Data Sources
CC begins by highlighting the data sources, primarily relying on the household travel survey and American Community Survey.

Use of big data
CC also mentions the emerging realm of big data, specifically the use of GPS trajectory data. Despite its potential, CC notes significant challenges with this data source, including incomplete trip chains and technical failures. The high costs of data

acquisition and storage further complicate its practical implementation. While big data presents a promising avenue, these challenges underscore the importance of refining data collection methods for comprehensive and accurate results.

Survey Design and Methodological challenges
CC discusses integrating questions about Mobility as a Service (MaaS), remote work, and flexibility into household travel surveys. However, the conversation transitions to the complexities of survey methodologies. CC discusses the shift from telephone-assisted to computer-based surveys in the US, which potentially led to biases in responses. Moreover, issues arise when combining panel-based and sample-based data, highlighting the importance of rigorous methodological approaches to maintain data quality and representativeness.

Ethical Considerations and Privacy Concerns
CC mentions that they are mindful of the privacy implications, especially when dealing with geolocation data. Our research adheres to Institutional Review Board (IRB) compliance, ensuring that ethical protocols are in place to safeguard participants' privacy and data integrity. These measures are essential to maintain responsible and ethical data usage in our research efforts.

Methods

Navigating the transition to Activity-Based Models
In this conversation between CC and JK, CC provides valuable advice on initiating activity-based models, specifically focusing on the methods involved in population synthesis. JK seeks guidance on where to begin, considering the complexity of methods like Bayesian networks and machine learning in contrast to the more familiar Iterative Proportional Fitting (IPF) approach. CC emphasizes that the choice of method depends on the available expertise within the team.

CC suggests starting with IPF, a method widely used and understood in transport modelling. She mentions publicly available software, possibly referring to the tool developed by Rampantiala, making IPF accessible to beginners. CC highlights the importance of understanding the underlying mechanisms and data organization, which serve as the foundation for any population synthesis method. According to her experience, students can grasp IPF within a few months, indicating that it provides a solid starting point for learning the essential concepts of population synthesis.

CC also notes the availability of Bayesian network tools on platforms like GitHub, indicating the growing accessibility of advanced methods. She underscores the importance of teaching and learning about the data and the fundamental principles of population synthesis. According to her perspective, once the team comprehends these core concepts and has a well-organized dataset, transitioning from one method to another becomes feasible.

This advice underscores the significance of foundational knowledge and data management in the realm of AABMs, providing a clear roadmap for beginners looking to delve into this complex field.

Selecting modelling tools

In this segment, JK and CC discuss the selection of modelling tools and the challenges associated with them. JK questions CC's choice of MatSim over ActivitySim, to which CC reveals not having tried ActivitySim. CC suggests ActivitySim for potential future use in Dubai and mentions RSG's involvement, hinting at open-source possibilities. The conversation shifts to concerns about software dependency and the preference for open-source solutions among governmental entities. CC highlights that consultants might share code, emphasizing the importance of open access due to the use of public funds. The discussion also touches on the population size in Maryland, around six million, and the computational limitations requiring the use of restricted samples in MatSim. This conversation underscores the complexities and considerations involved in selecting appropriate modelling tools for transportation studies.

Population size and computational challenges

CC mentions that the population size in their Maryland model is approximately six million. However, running MatSim for such a large population requires limiting the simulation, often working with a percentage of the population due to computational constraints. Achieving convergence in activity-based or agent-based models, given their complexity, remains a challenge.

Study area and model complexity

CC states that their study area focuses on Maryland and although a buffer zone exists, this has not been fully done because of the lack of staff/ team which is too small. In addition, the detailed intricacies of traffic passing through are not incorporated. The model primarily serves research purposes and isn't yet used for comprehensive traffic analysis.

Addressing stochasticity

In this part of the conversation, JK asks about how stochasticity is managed in the models. CC admits that they haven't addressed this aspect yet. JK discusses the Dutch practice of ensuring reproducibility, where consultants' results must be replicable using the same data, parameters, and model options. He wonders if this is achievable with activity-based models. CC acknowledges the challenge, stating that they are attempting validation but lack a sufficient baseline for comparison. When asked about the challenges of calibrating simulation-based models, CC defers, noting that their expertise lies more in demand modelling and data calibration rather than the technical intricacies of simulation calibration, mentioning issues with queuing in MatSim without delving into details. This exchange highlights the complexity of ensuring reproducibility and calibration in simulation-based transportation models.

Challenges when transitioning from trip-based to activity-based models, both in terms of organisation and technology

- Complexity and resource intensity: Activity-based models are significantly more intricate than traditional four-step models, requiring estimation of numerous models. This complexity poses a challenge, particularly in terms of the computational resources and time needed for running and validating these models.
- Lack of integration: Activity-based models are not seamlessly integrated into platforms like ZoomCube or TransGuard. This lack of integration complicates the

development process, requiring expertise in programming languages such as Java or Python, both from a development and user perspective.

- Resource intensiveness: Running activity-based models demands substantial time, often extending to days or weeks. Additionally, debugging and validating these models present considerable challenges due to their intricacy.
- Determining responsibility: There's a question of who should undertake this complex work. Historically, consulting groups handled such tasks, but the shift towards academia is suggested. However, CC notes that academia tends to focus on publishing papers rather than full-scale model development, indicating a potential gap in knowledge transfer.

CC advocates for a collaborative approach, combining the expertise of both consultants and academics. He emphasises the need for shared knowledge in the Netherlands and proposes a model where funding supports collaborations between universities and companies, allowing academic research to be practically applied and ensuring a continuous flow of new knowledge. CC highlights the successful model used in Dubai, where collaboration between academic institutions and companies like PTV has led to the development and implementation of advanced modelling techniques. She also suggests that universities should focus more on practical application and development rather than excessive paper publication to facilitate effective knowledge transfer and development in the field.

Future of Activity-Based Models
Looking ahead, CC emphasized the need for model simplification. She emphasizes the need for manageable models with modularity, allowing for easier additions or modifications without starting from scratch. They envisioned a future where activity-based models seamlessly intertwine with assignments, providing a unified approach to transportation modelling. CC highlights the need for integrating activity-based models with assignment, calibration, and validation processes. She notes that currently, demand and assignment exist as separate entities, and merging them would be a significant advancement in the field.

Explaining Complexities to Clients
JK asks about how CC explains these intricate models to clients. CC mentions using frameworks like RSG or ROV, which provide clear structures. She acknowledges the need for client education but believes that with effort, these complexities can be effectively communicated to clients, especially with the availability of reusable frameworks.

5.17 Ben Stabler

Ben Stabler is Senior Director of Data Governance at Motionworks AI Inc.

Definitions

Model definitions
BS defines activity-based models as econometric tools used to generate synthetic travel and activity diaries, a method influenced by the likes of John Bowman and Moshe Ben Akiva. These models construct a skeleton of an individual's day and populate it with trips and tours based on pre-estimated econometric logit models, comprising an intricate web of equations to simulate travel patterns.

Agent-based models, on the other hand, BS describes as more simplistic and adaptive, drawing from examples like MatSim and Kay Axhausen-style simulations. These models are centred around network-based simulations where agents (the entities within the model) learn through interaction with a set of rules and through experiencing the network, usually involving simpler cost functions, and requiring longer run times due to their learning nature.

Understanding agents
The discussion then shifts to understanding agents within these models. BS clarifies that in agent-based modelling, agents are typically represented by people with day plans and schedules that they aim to fulfil. While BS does not traditionally consider vehicles as agents since they do not make decisions independently, he acknowledges the potential for AI vehicles to be considered as agents in the future.

Model adaptability
Regarding adaptability, BS suggests that both activity-based and agent-based models can incorporate mechanisms to adapt to changes, like traffic delays affecting a person's schedule. By simulating different scenarios, these models can recalibrate to reflect the utility of completing daily tasks and explore alternative routes or schedules to mitigate disruptions, highlighting the responsive design that modelling requires.

Model complexity
Lastly, BS touches on the complexity of agent-based models compared to activity-based models, noting that agent-based models tend to be more intricate and require more computational effort. Despite this, he emphasises the importance of sensitivity and responsiveness in models to ensure they remain effective under varying scenarios and future contexts.

Towards AcBMs

Advancing modelling techniques
BS advises that the transition from trip-based and tour-based models to activity-based and agent-based models should be guided by the questions one seeks to answer. If the focus is on contemporary transport issues like multimodality and shared transport impacts, models need to accommodate the flexibility of mode switching and mobility-as-a-service solutions.

Network and routing
BS differentiates between policy-driven questions and network problems, suggesting that routing issues align more with network-based problems, whereas policy questions could delve into population changes and e-commuting patterns. He emphasises the importance of addressing the 'greying' of the population, changes in young people's mobility, and evolving shopping behaviours.

Model suitability
When it comes to network routing and adaptability, BS suggests that agent-based models are more adept due to their experience in building adaptive routes and testing modal changes. However, for generating diaries and projecting future behavioural trends, activity-based models are preferred as they construct day patterns like 'Legos'.

Realities of implementation
BS acknowledges that while there is a desire to encompass all modelling aspects, practical constraints such as computational run times and data requirements must be factored in. The goal should be to tailor the tool to answer specific questions effectively while managing expectations around data and run times. Additionally, the complexity of these tools often means that only a few individuals are skilled enough to utilise and maintain them properly.

Policy assessment
BS discusses the range of policies evaluated using activity-based models, which includes a broad spectrum from traditional highway and transit projects to more nuanced studies like pricing, equity, and e-commuting. The versatility of activity-based models is highlighted, allowing for analysis sensitive to income and other demographic factors without the need for foundational restructuring required by trip-based models.

Modelling issues

Disaggregate modelling
Both activity-based and agent-based models operate on a disaggregate level, providing the flexibility to describe populations in detail and summarize findings post-simulation. This contrasts with aggregate models, which necessitate pre-defined population segments, restricting the ability to adapt to changes.

Model flexibility
BS emphasises the flexibility offered by disaggregate frameworks in activity-based and agent-based models, enabling researchers to address novel policy questions and to be creative with data dimensions. This is important when tackling emerging transportation phenomena like autonomous vehicles and shifts in commuting patterns, which challenge the fixed structural relationships of traditional models.

Incremental approach
BS suggests an incremental approach to transition towards activity-based and agent-based modelling. This could involve starting with a disaggregated synthetic population and gradually moving towards more complex elements. He advocates for control and understanding in each step to avoid the overwhelm that can come with too many simultaneous changes.

Practical over theoretical

The conversation touches on the gap between theoretical perfection and practical application. BS points out that while there is ample theoretical work on disaggregate transport modelling, the challenge lies in its practical implementation. He recommends using established frameworks, like the ActivitySim project, to professionalize and standardize the industry, allowing for broader use and better maintenance of the models.

Population synthesis

On population synthesis, BS discusses the use of techniques like Iterative Proportional Fitting (IPF) and suggests starting with existing tools before moving to more complex methods like Bayesian networks. He acknowledges the computational limitations of IPF when dealing with multiple dimensions but notes that these can be managed with sufficient computational resources.

Computation constraints

Finally, BS recognises the constraints of computation time and resource needs, especially as models grow in complexity. He mentions the necessity of robust computing power, such as machines with substantial RAM and processing capabilities, to handle large-scale population synthesis and activity-based modelling. He emphasises the importance of not just the computational power but also the management and maintenance that these advanced models require.

Cloud-based modelling

BS is an advocate for cloud-based modelling, moving away from desktop dependency due to the sophisticated computational needs of modern models. He envisions running complex models in mere minutes with the right hardware, offering the potential for rapid scenario testing, which public agencies are often slow to adopt due to capital cost concerns and resistance to change from traditional tools.

Scalability challenges

A key issue highlighted by BS is the transport modelling industry’s struggle with scaling under pressure. He expresses frustration with the industry's inability to adapt quickly for urgent studies, which can lead to disregarding modelling insights. Cloud solutions could address this by allowing models to scale as needed, enabling agencies to run multiple scenarios simultaneously without infrastructure constraints.

Management considerations

BS also touches on the practical aspects of cloud computing, such as software compatibility and data sovereignty. He acknowledges that European agencies prefer data hosted within Europe due to management and privacy concerns, which are significant considerations when deciding on cloud services.

Market vs centralization

There is contemplation over whether countries should move away from market-based solutions to develop their own centralized modelling platforms, ensuring uniformity and scalability. BS aspires to create a comprehensive online platform for activity-based modelling but recognizes the industry’s resistance due to its boutique and research-oriented nature.

Collaborative efforts
Finally, BS reflects on the challenges of cooperation among agencies and the potential benefits of pooling resources. He notes that collective investment decisions often focus on immediate needs rather than broader industry progress. The discussion acknowledges the difficulty in aligning the goals of a collaborative project with the individual objectives of participating agencies.

Global collaboration
BS advises Dutch agencies to look beyond national boundaries for knowledge and model development due to the limited scope for growth within the Netherlands. He stresses that the global market cannot support many different versions of advanced traffic models and suggests that a few well-developed ones would serve better.

Open-source transition and cooperation

Open-source approach
He supports the transition to open-source platforms, particularly for the transportation demand aspect of modelling, to avoid dependence on costly proprietary software that requires specialized knowledge. BS sees the value in an open-source approach that would allow a broader community of users and developers to contribute to and benefit from the model's evolution.

Software independence
BS resonates with the aim to not become reliant on a few software companies. He highlights ActivitySim's mission to provide a scalable, freely available platform that encourages agencies to become contributing members and support the cooperative model.

International participation
Confirming the international reach of ActivitySim, which includes participation from Canadian and potentially Australian governmental bodies, BS encourages Dutch governmental bodies to join, indicating a willingness to support international collaboration. This approach aligns with the need to build a community around shared tools and resources, which could be a focus for future projects.

Transition complexities
BS cautions that shifting from trip- and tour-based models to activity-based models involves significant challenges, including extended timelines, increased costs, and unexpected difficulties. He notes that it's common for agencies to maintain their old models during the transition for comparative learning purposes. The need for more detailed data is emphasized to support the intricacies of the new systems.

Technical skills
The technical skills required for modern transport modelling are substantial, with a preference for more accessible programming languages like Python over complex ones like Java. BS's vision with ActivitySim was to create a user-friendly, Python-based platform to facilitate wider adoption without the need for deep programming expertise.

Modeler or engineer
BS identifies himself as both a transport modeler and a software engineer, acknowledging the rarity of this combination. He underscores the difficulty in finding professionals who possess both the domain knowledge of transport modelling and the technical proficiency to handle complex software issues.

Division of labour
There is a discussion about whether transport modelling in the Netherlands, which often relies on pre-packaged software like Omnitrans, should progress towards a combination of open-source platforms and bespoke development. BS suggests that having solid software engineering skills accessible is vital, whether in-house or through consultants, especially as new applications of the model are explored.

Government modelling role
BS recognizes that in many government settings, there is a separation between those who manage the models and those who apply them, with the former often lacking the time to engage in hands-on modelling work. He stresses the importance of using mature, well-documented tools with robust user communities to handle the complexities involved.

Programming and management
Reflecting on past experiences with Fortran and the evolution of software development practices, BS contemplates separating software engineering from transport modelling. Modern software development requires rigorous management and version control, which may necessitate a division between those who understand the modelling process and those who can develop complex programs.

Final thoughts
In the final moments of the discussion, BS is open to addressing any additional questions, but he also indicates the need to conclude soon due to other commitments.

big data integration
BS predicts that the integration of large data sets will play a significant role in the development of activity-based and agent-based models. The shift towards models that dynamically respond to real-time data is expected to continue and become more sophisticated.

Open-source advancement
The future is seen to hold a proliferation of open-source tools in transport modelling. Projects like MatSim and ActivitySim are anticipated to grow and improve, with an increase in community involvement. BS suggests that investing in these tools is a prudent decision.

Cloud migration
There's a clear inclination towards cloud-based solutions, which BS sees as beneficial for making models more accessible to stakeholders. He believes that the cloud infrastructure will enable more efficient and collaborative use of modelling tools.

Modelling novelty
Lastly, BS finds excitement in the challenge of modelling new structural shifts, such as those brought about by autonomous vehicles. These changes present complex problems to solve, requiring innovative simulation systems. While acknowledging the complexity and initial messiness, BS highlights the opportunities these developments present for keeping the modelling community engaged and forward-thinking.

5.18 Charlene Rohr

Charlene Rohr is Technical Director at Mott MacDonald.

Understanding activity-based and agent-based models

In this interview, CR offers her insights into activity-based and agent-based models from an organizational perspective. She sees these models as two distinct dimensions within the field of transportation planning. Activity-based modelling primarily focuses on accurately representing the various activities that individuals engage in during their daily lives, which may or may not involve transportation. These models aim to establish better connections between the decision-making processes related to activities, such as going shopping or working from home. They also delve into the choice between out-of-home and within-home activities, as well as the scheduling of activities throughout the day. Traditional tour-based models, CR notes, fail to adequately address these elements, as they do not account for whether people opt to perform certain activities and how they organize them.

CR highlights that agent-based modelling is often closely associated with activity-based modelling, particularly in the United States. Still, she acknowledges that they are not entirely intertwined, as some agent-based models do not incorporate activities. Agent-based models introduce the concept of individual agents within the model, which allows for a more detailed understanding of the specific choices made by these agents. This increased granularity can be advantageous in scenarios where precise information on geography, socioeconomic conditions, or value-of-time distributions is necessary, such as when designing road user pricing policies. CR underscores that agent-based models offer unique advantages beyond the activity-based structure.

Agents and individuals

The discussion further touches on the use of the term "agents" in these models. CR clarifies that when considering travel demand models with activities, the term "agent" refers to individuals. However, she also entertains the idea that agents could encompass other entities, such as vehicle providers or suppliers, like bus companies in the UK, within the model. Nevertheless, when specifically discussing agent-based or activity-based models, the focus primarily lies on understanding the behaviour of individuals and their travel choices, including trip decisions and mode preferences. In this context, a car or vehicle may be considered an agent, but it does not fully align with the activity-based framework, which discusses aspects like working from home and other daily activities. Agent-based and activity-based models are primarily concerned with understanding and modelling individual behaviour in the context of transportation planning.

Selecting model types for transport planning: A contextual approach

In this interview, CR discusses the choice between activity-based and agent-based models in the context of transport planning. The decision to adopt one model over the other depends on the specific objectives and problems that need to be addressed. CR advises that the choice should be driven by the real-world problems the models can help solve. For example, in the case of urban areas, where understanding how people make trip-chaining decisions and whether they work from home impacts other travel choices, activity-based models can be valuable. She cites an example from the UK's National Highways, where changes in travel behaviour due to COVID, like people working from home, led to shifts in trip patterns, highlighting the importance of understanding these changes.

CR emphasizes that the relevance of activity-based models can vary based on the area being studied. For long-distance intercity trips, such as those managed by National Highways, the importance of trip-chaining and detailed activity modelling may be less significant. However, she acknowledges the uncertainty in this regard and suggests that the choice of model should align with the specific problems and policies that need to be assessed in the future. For instance, an agent-based approach might be more suitable for clients like National Highways, who are interested in road user charging policies and understanding payment behaviour.

The conversation references Leonid Engelsson's views on the potential limited utility of activity-based models for long-distance trips, particularly in Sweden, and CR agrees that her instincts align with this perspective. She acknowledges that her opinion is based on instinct rather than empirical evidence. However, she points out that the Dutch Department of Transport, especially in the central Netherlands, appears to be more inclined towards activity-based models, addressing detailed questions related to transport, inclusivity, and gender-related aspects. The choice between model types is driven by the specific regional context, and while cities and urban areas may benefit from activity-based models, long-distance models may lean towards trip-based models. The key takeaway is that the model choice should be tailored to the specific issues and policy considerations relevant to the region or area under study, acknowledging the diversity of challenges within the field of transport planning.

Data challenges and opportunities

The conversation begins with a focus on data sources, emphasizing the importance of data in the context of activity-based modelling. CR notes that her primary experience lies with Household Travel Survey data, which provides valuable insights into travel behaviour. However, she highlights that these surveys often lack detailed information about activities conducted from home, which is important for understanding choices related to working from home, online shopping behaviour, and other activities. While mobile phone data can offer extensive information, it lacks the level of detail about individuals. CR mentions emerging practices of combining mobile phone data with travel survey data to estimate models, but she remains sceptical about whether this approach can fully replace the need for comprehensive travel survey data.

TAG (Transport Appraisal Guidance)

The conversation then shifts to TAG, the transport appraisal guidance provided by the UK's Department for Transport. CR describes TAG as a "recipe book" for practitioners and clients involved in transport model development. TAG offers guidance on setting up models, validating models, selecting parameters, and much more, effectively serving as a framework for the development and appraisal of transport models. While TAG provides a structured approach to model development, it also raises questions about its potential to stifle innovation. CR highlights that TAG can constrain innovation by discouraging deviations from its prescribed parameters and model structures. This constraint may hinder the exploration of new modelling approaches and ideas.

TAG's impact on population forecasting

Regarding population forecasting, CR notes that TAG does not extensively cover this aspect. Instead, the UK government provides separate TRIP forecasts that are fed into the models. This approach poses challenges for activity and agent-based models as they require more detailed and controlled population data. To address this, CR suggests that the UK is considering a population forecasting, synthesizing, and sample enumeration approach. This approach allows for greater control and granularity in population data, essential for activity and agent-based modelling.

Solutions and open-source models

As a potential solution to the challenges posed by TAG, CR proposes a tiered system like the Dutch model, where there are multiple tiers of models, including a national model and regional models. These models can feed from higher-tier parameters and be open source, allowing different users to access the level of detail they need. This approach promotes consistency while accommodating regional variations and reducing the financial burden on different regions to develop models from scratch. However, it is essential to consider how such a system could be implemented within the existing framework.

Updating TAG and the role of consultants

CR acknowledges that TAG is periodically updated through competitive tenders, where consultants bid to revise and maintain the guidance. Winning this work is seen as prestigious within the industry because it provides control over the guidance. This competitive nature of TAG updates has advantages but also drawbacks, as it may limit the diversity of input and innovation. CR suggests that involving competitors, academics, and open-source collaboration in TAG updates could enhance the guidance and promote a more innovative and adaptable approach.

TAG at the national level

The discussion begins with an exploration of TAG's organizational structure. CR explains that TAG is primarily organized at the national level in the UK. However, she acknowledges that discussions about model development and national strategies often involve input from cities and regions. While there is room for cities to make their models compliant with TAG, the challenge lies in aligning city-level models with the broader national structure. It is noted that there are no imminent plans to change this organization, and it largely depends on cities to determine how TAG-compliant their models need to be.

Model development in a smaller country

The conversation then shifts to the context of the Netherlands, a smaller country in comparison to the UK. CR suggests that whether a smaller country like the Netherlands needs a system like TAG depends on its existing models and regional structures. Larger cities may benefit from TAG-like guidance, but smaller cities might be better integrated into a national or regional framework for model development.

Management and maintenance of models

CR brings up the topic of model management and maintenance, emphasizing the importance of maintaining and updating models over time. In the context of the Netherlands, discussions revolve around the practicality of model application and results. Questions arise about data elasticity, result storage, version control of models, and long-term management of models. CR points out that TAG does not explicitly cover maintenance procedures and suggests that adding guidelines for model management and maintenance could be a valuable addition to TAG.

Collaboration and academic involvement

The interview touches upon the importance of collaboration between governmental entities, consultants, and academic institutions. CR expresses the benefits of working with academics who are interested in large-scale modelling problems, even though they may sometimes focus on different research areas. The discussion highlights a gap between governmental entities, academic research, and consultancy, emphasizing the need to bridge this gap for effective and robust model development. CR cites examples from Scandinavia, where academic institutions are actively involved in travel demand modelling research. However, she acknowledges that finding academics with a specific interest in large-scale travel demand modelling can be challenging, especially in the UK.

The interview moves on to an agreement on the importance of closing the gap between academic research and practical application in modelling and exploring innovative procurement strategies to encourage model development and maintenance. The discussion underscores the significance of effective collaboration and management practices for the successful development and application of transport models.

Policy concerns and unpredictable scenarios

CR begins by expressing her viewpoint from a policy perspective, highlighting her reservations about the true value of detailed activity-based models. She questions whether these models can adequately address future uncertainties, such as the shift towards remote working or the impact of autonomous vehicles. CR suggests that while activity-based models can provide insights into specific scenarios, they might not offer a complete understanding of broader trends, like climate resilience, which are essential for effective policymaking. This leads her to question whether a disproportionate emphasis on detailed models might divert modelers from addressing more significant and critical questions.

Complexity and underpinning policy measures

The discussion touches upon the complexity of activity-based models, with CR mentioning the need to understand human behaviour, especially in the context of evolving phenomena like e-commuting. The broader themes of climate change, COVID-19, and geopolitical uncertainties are highlighted as challenges that always pose dilemmas. CR emphasizes the need to consider these issues in the background scenarios that underpin transport models. She questions whether it's worth focusing extensively on the minute details of individual behaviour rather than addressing these macro-level problems.

The balance between detail and scenario models

As the conversation unfolds, CR explores the idea of maintaining a balance between detailed models and scenario-based models. She envisions a scenario where different tiers of transport models coexist, including tour-based, activity-based, and scenario-based models. These models would cater to varying needs and timescales. The scenario models, which are faster and less detailed, would provide a more approximate, elasticity-based framework that captures a wide range of possible future scenarios. The idea is to allow these models to interact and complement each other, addressing both policy specifics and broader, unpredictable scenarios.

CR's perspective calls for a re-evaluation of the emphasis on the level of detail in transport models, focusing instead on their applicability in diverse scenarios and their role in addressing significant, evolving challenges. While the role of detailed models is recognized, CR suggests a potential shift towards a more balanced modelling framework that could provide insights into both policy measures and the uncertainties of the future.

Closing thoughts on the interview

In the final section of the interview, CR and JK discuss the allocation of resources in transport modelling and the future direction of the field, with a focus on addressing the needs of different population groups.

Resource allocation and future direction

CR emphasizes the importance of allocating limited government resources thoughtfully, especially in a field like transport modelling where uncertainties abound. While there is a fixed amount of funding available, the optimal direction for development remains uncertain. The discussion, conducted through these interviews, provides valuable insights into this complex decision-making process. The aim is to make sound choices guided by the pressing challenges of the future, and not just driven by the ability to develop models for the sake of it.

Prioritizing policy measures

CR's advice for governments is to align model development with future real-world challenges and the necessary policies and investments to address these challenges effectively. Rather than focusing on extensive model improvements simply because they are technically feasible, the emphasis should be on using modelling to address critical policy and investment decisions.

Balancing detailed models and scenario models

The conversation briefly touches on the idea of achieving a balance between detailed models and scenario models. The consensus is that scenario models, designed for speed and efficiency, could play a crucial role in understanding the impacts on various population groups. While detail is valuable, there is also recognition that understanding impacts on different segments of the population can be equally essential.

Agent-based models and population characteristics

MP raises the idea of incorporating agent-based models or synthetic populations in modelling approaches, emphasizing their flexibility and suitability for distinguishing between different population groups. CR and JK express their agreement with this notion and highlight the importance of detail in synthetic populations to facilitate more comprehensive and nuanced analysis.

5.19 Pascal Boonstra & Michiel van Bokhorst

Pascal Boonstra is Advisor on Spatial Planning and Mobility at the Municipality of Almere, Michiel van Bokhorst is Strategic Policy Advisor on Sustainable Mobility at the Municipality of Almere.

Overview transport model Almere

Introduction
PB provides insights into the transport model used in the city of Almere. The model in question is primarily a tour-based transport model with some agent-based elements, focusing on inner-city travel and the residents. The model integrates various demographic data, including age groups, employment, types of education, and housing. It was last updated in 2018-2019, and there is ongoing contemplation about its future. Additionally, PB mentions the development of a model for Flevoland, which is still in its early stages and facing challenges, highlighting the current crossroads in their model development.

Agents in the model
PB clarifies that their model does not individually represent each person in the city. Instead, they populate the model using data, such as age groups, from sources like ODIN and the Nationaal verplaatsingspanel (NVP). This approach creates groups of individuals with specific characteristics like age, income, gender, and more. The goal is to replicate and predict mobility and location choices based on this data, not to model every single person. This strategy positions the model as a hybrid between a tour-based and agent-based model, with a pathway towards a more agent-based approach in the future.

Transport model components
In general, a transport model comprises two main components: the transport demand (tour-based model) and the traffic demand (assignment model). Concerning transport demand, the model considers cars, public transportation, and cycling. The model performs an assignment for each mode. For cars, they distinguish between regular, medium-heavy, and heavy vehicles. In terms of cycling, they include a comprehensive network with extensive data on the main cycling routes, ensuring a robust representation of the city's cycling infrastructure.

Network detail and validation
The model's cycling network is highly detailed, including most major routes and key counting points on the primary cycling network. Smaller pathways are omitted, given their limited relevance. The presence of canals and highways in Almere allows for easy data collection points, which enhances network validation. They employ an annual counting program with 56 counting points, as well as continuous monitoring of one single main route. This approach aims to provide a robust and valid model that can yield meaningful insights for the city's transportation planning.

Multimodal approach
The Almere model follows a multimodal approach, covering road-based travel, cycling, and public transport. These modalities can be analysed independently if necessary, offering a flexible and comprehensive perspective on the city's transportation system.

Software platform
They utilize the OmniTrans 8 software (version 8.06), with Octavius running in the background. The Octavius population synthesizer is primarily applied to internal zones within the transport demand model, not to zones in external locations like Amsterdam. The model's stability is commendable, especially since it's a relatively new system, and any issues are swiftly resolved due to their close collaboration with model developers.

Model computational times and feedback
The model runs on remote hosting servers to ensure consistent performance. The computational times for the model are quite reasonable, with a demand model taking approximately 12 to 24 hours and a separate assignment model for a single mode requiring just a morning's work. The population synthesizer, zone adjustments, and other corrections consume substantial processing time. Overall, running the entire model with all modalities assigned takes about 12-24 hours.

Modelling policy measures

Modelling and policy questions
PB highlights how the model has evolved over the years, enabling in-depth analysis of various policy questions. It emphasizes the importance of fine-grained demographic data, including age groups, car ownership, and more. This level of detail aids in addressing specific policy issues such as increasing parking norms or designing transportation solutions for student campuses. PB also underscores the value of more detailed modelling when dealing with developers, though it does introduce some complexities in obtaining detailed data for new developments.

Network versus transport demand questions
PB discusses the balance between network-related questions, like new road connections, and behaviour-related queries. PB reveals that both types of questions are addressed within the model. Network-related questions often involve changes in road infrastructure, while behavioural queries tackle transportation demand issues, including changes in car ownership and travel patterns. The model is a vital tool for investigating the impacts of these policy decisions and helps in creating a nuanced view of urban transportation.

Parking policies and costs
Concerning influencing parking policies, both in terms of parking norms and costs, PB emphasizes how the model can be used to regulate car ownership in specific areas by applying different norms and parking costs, tailored to the demographic composition and transportation infrastructure. MP makes distinction between parking prices and costs, with the importance of an activity-based approach for accurate modelling. Prices (parking tariffs) concern the supply side and costs the demand side of the model.

Defining public transport hubs
PB discusses the concept of public transport hubs and their role in the model. There's a distinction between simply having public transport stations and defining a public transport hub. While hubs typically involve various transportation modes converging,

PB raises questions about what truly constitutes a hub in the context of the model. PB acknowledges that defining hubs remains a complex task, especially when considering the interconnectedness of spatial developments, office spaces, retail, and recreation around these hubs.

Public transport simulation

The focus then shifts to public transport simulations, which are used to boost the number of car journeys and include stations and stops for various modes. These simulations aren't precisely calculated but involve pre-determined values for vehicles to approximate their effect on auto travel.

Bicycle modelling

PB sheds light on the limited incorporation of bicycles within Almere's transport model. The model occasionally considers bicycle routes when assessing the impact of road changes. However, it's made clear that comprehensive network studies for bicycles aren't currently a standard practice in Almere yet. The existence of a calibrated bike matrix is acknowledged, leaving room for optimization of the model's use in this regard.

Walking and future developments

While walking as a mode isn't heavily featured in the model, it's noted that it might gain more attention in the future, especially in areas with significant pedestrian activity. PB ends with a glimpse of the city's future for the transport model, including the possibility of regional collaboration, continued participation in the 'Venom' model, and the consideration of a future model re-tendering process. These evolving dynamics will shape the city's transport model in the short and long term.

Other topics

Data and model management

Discussions cover the role of management for model results, data and software. They use data from the National Travel Survey and ODIN and handle most calculations in-house. PB highlights the importance of keeping versions and results in check, and they're considering developing a format for third-party consultants to report model issues.

big data and model development

PB mentions the use of GPS data and possibly other big data sources for the model's base matrix, though the technical details are left to experts. Questions about stochasticity and Monte Carlo simulations reveal that this is not an issue in Almere. This situation differs from the initial start of the model, but results were improved. Nowadays, assignments lead to the same outcomes every time they are applied.

Definition activity- and agent-based modelling

The discussion briefly explores the definitions and distinctions between activity-based and agent-based modelling. While there's some ambiguity around these terms, the general understanding is that activity-based modelling discusses the specific activities that individuals perform during the day, while agent-based modelling simulates individual behaviours and decision-making related to travel.

Collaboration and future considerations
Almere collaborates with the Metropolitan Region of Amsterdam, the Province of Flevoland and the Municipality of Lelystad. Their partnership with the 'Venom' model focuses on data and knowledge sharing, while the exploring collaboration with Flevoland and Lelystad is predominantly driven by financial considerations and software idea exploration. The interview touches on examining vendor lock-in challenges and potential solutions for developing a more platform-independent transport model. The possibility of developing a separate transport demand model. With those parties is considered here as well.

Closing thoughts
PB firmly asserts that Octavius, despite having some features reminiscent of activity-based models, falls more within the tour-based category. He highlights that Octavius lacks the granular detailing, notably the duration of activities via an activity scheduler, that characterizes true activity-based models. The significance of time and interdependencies is a key defining factor, which Octavius doesn't fully encompass.

PB emphasizes the need for clarity and standardized definitions in the modelling field, citing various experts' perspectives. He advocates for a more precise understanding of what constitutes activity-based, agent-based, or tour-based models. PB underscores that clarity on these distinctions will aid in determining the extent of improvement and representativeness within Almere's model.

In wrapping up the discussion, PB asks about the advice and recommendations that Almere might seek regarding their model's future development. He suggests that the ultimate value of an activity-based model is the ability to incorporate aspects not previously considered in traditional trip or tour-based models. This includes addressing elements like micro-mobility, shared mobility, and other urban transportation trends.

5.20 Maaike Snelder

Maaike Snelder is Principal Scientist at TNO and Associate Professor at the Delft University of Technology.

Activity-based and agent-based models: an academic perspective

Defining activity-based and agent-based models
MS begins by distinguishing between activity-based and agent-based models. She defines activity-based models as those capable of generating activity patterns independently, emphasizing the addition of activity components compared to standard strategic models. The key question is how to achieve this. She notes that so far, she has only seen agent-based models accomplishing this task, with some debate over the term "agent." These models are often microscopic in nature, generating activity patterns for individuals, where "agent" represents individuals and "activity" stands for activities.

Agent-based models and transport modelling
MS explores the notion of agent-based models within the context of transport modelling. There is some contention about what constitutes an agent, as some may argue that an agent should be an autonomous entity capable of communication with others. However, MS clarifies that this is not a strict definition. Agent-based models can also be microscopic in nature, but their application at a large scale remains challenging. Therefore, activity-based models are often integrated with agent-based models, especially in microscopically allocating transportation resources. MS mentions examples such as MADS and large-scale micro-simulation, emphasizing the need to bridge the gap to large networks.

Defining agents and their application
The discussion explores further into the definition of agents, with a focus on their application in transportation demand. While agents can be considered individuals in this context, the conversation also explores scenarios where agents represent vehicles rather than individuals. Additionally, MS discusses situations where individuals are assigned to vehicles, particularly in the context of shared transportation or ride-sharing services. These complexities demonstrate the ongoing evolution of agent-based modelling in transportation.

Population synthesis and household interactions

MS touches upon population synthesis, which involves creating agents that represent individuals. She highlights the ideal goal of linking these agents to households to model interactions within households. This task is not straightforward but is possible. The discussion emphasizes the importance of modelling interactions at various levels, from individuals to households, to better capture the dynamics of transportation demand.

Terminology and complexity
The interview concludes with a brief conversation about terminology. While "activity-based" and "agent-based" are standard terms, MS acknowledges that the field's nomenclature can become somewhat convoluted, especially when abbreviations are

used. Despite the challenges, these terms remain widely accepted within the academic community, providing a common language for discussing complex transportation modelling concepts.

Data requirements and sources for activity-based models

Current data adequacy in the Netherlands
The conversation starts with a reflection on the sufficiency of current household data in the Netherlands for activity-based modelling. MS acknowledges that the existing household data is quite good, suggesting that there may not be a significant need for additional data beyond what is already used for estimation and calibration. This prompts the question of whether the current data can meet the model's requirements effectively.

Challenges in data for temporal aspects
The interview explores specific challenges related to data, particularly in temporal aspects. The focus shifts towards departure times, arrival times, and the duration of activities. While the data might be generally adequate, there may be issues with capturing fine-grained temporal patterns, such as trips around midnight. MS speculates that this issue could be attributed to a lack of data fidelity, especially when participants fill out daily diaries.

Defining and refining boundaries
The conversation shifts to defining the boundaries of spatiotemporal aspects within activity-based modelling. It becomes evident that the challenges are more related to defining these boundaries than to data collection. MS suggests that the problem lies more in defining the boundaries and may not be primarily a data issue. The discussion highlights the need for a more precise delineation of these boundaries to improve the models.

Expanding beyond transportation
The interview briefly touches on the distinction between OVIN and ODIN, which prompts a discussion on the nature of activities that occur at home, which are not traditionally recorded. The conversation expands to consider activities like e-commuting, e-shopping, and e-learning, emphasizing the complexity of capturing the full range of activities. MS acknowledges the challenges in collecting this data and the potential need for additional surveys or data sources.

Time use surveys and data integration
The discussion introduces the concept of time use surveys as a potential solution to gain insights into people's activities. While MS is unfamiliar with the concept, it is suggested that such surveys could provide valuable information for activity-based models. However, it is acknowledged that the integration of data from various sources would be complex but necessary for improving the models' accuracy.

Leveraging detailed data and privacy concerns
The conversation discusses the use of detailed data from the CBS (Statistics Netherlands). While the detailed data from surveys offers richer information, privacy concerns restrict the direct extraction of linked data from the CBS environment. The conversation suggests that validation could benefit from combining this data with

information from ODIN and OVIN. Privacy is emphasized as an important consideration when working with such data.

Exploring big data and federated learning
MS discusses the application of big data and federated learning in their work, particularly in their research at TNO. They utilize various data sources for modelling travel behaviour, including factors like travel intensity, travel times, and the use of shared mobility services. The conversation highlights the potential of federated learning to utilize data from various sources while preserving privacy.

Looking ahead
The interview concludes with a discussion about the future of modelling and the importance of consistently aligning the models with other choice models. The need to consider data integration and maintaining model consistency is emphasized, as well as the ongoing developments and challenges in the field of activity-based modelling. The conversation mentions ongoing research and efforts at TNO in collaboration with Urban Tools Next.

Methods and cooperation in activity-based models

Evaluation of European initiatives
MS begins by addressing the multitude of initiatives in Europe, including Urban Tools Next, activity-based modelling projects in Copenhagen, London, Switzerland, Belgium, and more. The discussion revolves around the level of collaboration between these initiatives. While there is knowledge exchange, there hasn't been extensive cooperation in jointly developing or configuring a single type of activity-based model. Each initiative tends to work independently.

Challenges in Dutch expertise
The conversation discusses the limitations of expertise in the Netherlands concerning the development and application of activity-based models. MS acknowledges that there's a scarcity of experts in the field, which might hinder the development and application of such models for various government agencies. The need to broaden the expertise base is emphasized.

Addressing expertise challenges
The conversation touches upon strategies for expanding expertise. MS suggests that expanding the base of experts depends on the demand for application. If there is a need, the academic community can work on providing a broader foundation for people interested in working with activity-based models. This could be done through educational programs and research projects, focusing on activity-based modelling, and addressing specific needs.

Consultants' role and collaboration

Enhancing education and collaboration
The interview raises questions about education and collaboration within academic institutions. MS mentions that education on activity-based modelling is not shared collectively but can be initiated if there is a demand. Collaboration among universities is limited, and each institution manages its own research program. While cooperation

in research programs is possible, education is currently done individually, with TU Delft as an example.

Collaboration among academia and industry
The discussion moves towards the potential for collaboration among academic institutions, government agencies, and consulting firms. MS believes that collaboration is feasible when there is a shared goal of developing a model and establishing a common basis. The challenge lies in finding a suitable collaborative model that accommodates the diverse interests of academia and the private sector.

SIVMO's role
MS sees SIVMO as a potential catalyst for bringing together various stakeholders in the development of activity-based models. SIVMO could facilitate discussions among universities, government agencies, consulting firms, and other knowledge institutions, creating opportunities for collective efforts. The interview concludes with a shared interest in exploring potential collaboration models and boosting the development of activity-based models.

Consultants' business models
MS considers the possibility of reshaping the business models of consultants in the field of activity-based modelling. However, MS suggests that it's more appropriate for the consultants themselves to determine if such changes are necessary. MS also raises the idea of specialization among different actors, with each focusing on specific aspects and coming together to contribute to a comprehensive solution.

The Basgoed model and collaboration
MS mentions the Basgoed model as an example of collaboration and highlights the ways in which various parties work together. While some specifications have been established by TNO, the implementation is carried out by consultants and software companies, with market players involved in application. However, the participation of academic institutions is somewhat lacking in this collaboration, and there is room for improvement.

Expanding expertise and collaboration
The conversation discusses the need to broaden expertise within the field of activity-based modelling. MS emphasizes the importance of expanding the pool of experts, especially considering the limitations in the Netherlands. There is a call for more collaboration between various actors to build a foundation of expertise and address the challenges collectively.

Urban Tools Next as a catalyst
The interview highlights Urban Tools Next as a catalyst that brought different government agencies together. It has been a unique collaboration involving ten government organizations. MS acknowledges the positive outcome of this collaboration, despite TNO's exclusion, and sees it as a significant achievement in terms of working together on a large scale.

Challenges of agent-based models
The discussion shifts to methods, focusing on the transition from trip-based or tour-based models to agent-based models. MS mentions the challenges of moving entirely

to agent-based models, emphasizing that the process requires careful planning and gradual transitions. The first step is to focus on the population and gradually desegregate or make sub-models agent-based without completely overhauling the existing models.

Agent-based model implementation
MS talks about the challenges involved in agent-based modelling, including population synthesis. The conversation touches on the importance of stochasticity in the modelling process and the need to address re-sampling and stochastic aspects. The interview discusses the technical aspects of population synthesis and discusses potential solutions to overcome challenges.

Hybrid approach
MS considers combining agent-based and aggregated models. This hybrid approach presents challenges in determining the right balance between the two. The conversation acknowledges the complexity of such an approach and the need to gain experience in implementing it.

Relevance of the model's scale
The interview addresses the scale at which agent-based modelling should be implemented. MS suggests that while it might be feasible for the entire Netherlands, the decision depends on the computational resources available. GPU implementations can significantly reduce computational challenges. MS emphasizes that test areas outside the Netherlands might require adopting a different approach due to data limitations.

Population synthesis and runtime
MS touches on the time required for population synthesis. The duration depends on the geographical area and the specifics of the model. While the exact time is not specified, it's stated to be manageable in terms of hours or less. MS discusses the option of generating populations for a single forecasting year or considering a year-to-year simulation, both of which have their own complexities and advantages.

Year-to-year simulation
MS discusses the complexities involved in year-to-year simulations, focusing on aging populations, birth and death rates, and migration. Shifting to a year-to-year approach introduces more detailed considerations, such as the evolution of the population over time, which may require additional data and parameters to be integrated. The potential increase in complexity is acknowledged, and the discussion opens up various possibilities and challenges in modelling.

Population synthesis and model flexibility

Population synthesis
Population synthesis aims to create detailed representations of individuals, including characteristics related to vehicle ownership and other elements. The discussion considers the challenges of modelling these aspects year by year, emphasizing the complexity of such an approach. While acknowledging the potential difficulties, the suggestion is to transition from a base year to a future year, considering the complexity involved.

Year-to-year modelling and data collection
The conversation also touches on the data requirements of year-to-year modelling, particularly the need for more comprehensive and detailed data. The discussion highlights the challenges of data collection and the potential demand for new survey methods. The idea of synthesizing demographics is considered, with an emphasis on questions related to life events, such as when people buy cars, expand their families, or acquire larger homes. These considerations go beyond the typical demographic models and provide a deeper understanding of behaviour.

Challenges and potential pitfalls
There is a discussion about the potential limitations of fine-grained year-to-year modelling, and concerns are raised about the possibility of introducing a "false precision" that may not reflect real-world complexities. The complexities associated with managing demographic attributes and life events are recognized.

Towards the future
The conversation concludes by considering the potential future of modelling and data. The idea of using big data for calibration is introduced, with an emphasis on leveraging the patterns in data rather than specific attributes. The discussion acknowledges the need to explore ways of integrating various data sources, such as mobile phone data, GPS data, or TomTom data, to improve the quality of modelling. The potential benefits and challenges of transitioning from data-heavy calibration to pivot-point modelling are also explored.

Nesting structures in AcBMs
The conversation briefly touches on the topic of nesting structures within AcBMs. While many current models rely on pivot-point modelling, there is a discussion about the possibility of introducing more complex nesting structures in AcBMs. The practicality and computational implications of such a transition are considered, as well as the challenges related to sampling within nested models.

Challenges and software

Advantages and limitations of AcBMs
The interview concludes with a discussion of the advantages and limitations of AcBMs when compared to existing models. MS highlights the flexibility that AcBMs offer for modelling various measures and policies, especially those related to activities, trips, and mode choices. The interview emphasizes that AcBMs can provide a more comprehensive and flexible framework for analysing the impacts and indicators of different measures, allowing for more detailed and customizable analyses. However, it is acknowledged that stochastic elements pose challenges, and the discussion points out that AcBMs may require more sophisticated computational infrastructure. The interview also considers organizational challenges, particularly the need for further development and adaptation in Europe and the potential for a less agile system. However, the interview also highlights that these organizational challenges are not unique to AcBMs, as even current strategic models face similar issues in terms of adapting to changes and conducting testing.

Developing activity-based models: Considerations and existing tools

MS and JK discuss the need for different levels of AcBMs, one for practical implementation and the other for innovation and adaptation. There is mention of existing open-source packages that can be utilised for AcBM development but also a recognition of the initial effort required to understand and work with them. The interview emphasizes the potential for innovation and the need for customization while also highlighting that existing packages may not fully meet these requirements.

Choice of software packages and development
The interview touches upon the question of whether it is more viable to develop AcBM software from scratch or build upon existing packages. The preference is given to the latter, considering that many existing packages can be extended and adapted. MS emphasizes the importance of understanding and being able to modify the code within these packages for full customization. Activity Sim and MatSim are cited as examples, with Activity Sim being recognized for its strong activity component and MatSim's focus on assignment. The interview acknowledges the necessity of optimizing and potentially speeding up these packages to enhance their usability.

Collaboration and open source
The conversation raises the importance of contributing back to the open-source community when improvements or modifications are made to the code. While discussing the organizational and management aspects of open-source software, it is highlighted that the development of protocols and procedures is vital to the success of using and improving such software. The need for collaboration and being part of the open-source community is emphasized to overcome challenges and advance the field collectively.

The role of complexity in models
The final discussion centres on the impact of complex models on the quality of answers and decision-making. MS suggests that the level of complexity should align with the nature of the questions being addressed. While some questions can be effectively answered with more abstract and aggregated models, others require the detail and flexibility offered by AcBMs. The need for improved models and better answers justifies the effort put into model complexity, though it is noted that practicality and suitability for specific questions are essential considerations.

Scale and practicality
The interview concludes with considerations related to the suitability of AcBMs at different scales, such as urban or regional levels. MS suggests that the appropriateness of AcBMs may vary based on the questions and context. Different organizations and authorities may find AcBMs more practical depending on their specific goals and needs. The influence of scale and the practicality of AcBMs at different levels is recognized as a topic for further exploration and understanding.

5.21 Soora Rasouli

Soora Rasouli is Professor at the Eindhoven University of Technology.

Understanding activity-based and agent-based models

Activity-based and agent-based models
SR differentiates between activity-based models and agent-based models from an academic standpoint. She characterizes agent-based models as simulations that require assigning specific behaviours to agents, allowing for scenario analysis based on those behaviours. On the other hand, activity-based models focus on predicting future behaviours, acting as a precursor to extracting behaviours for agents in agent-based models.

Defining agents
When asked about the definition of agents in agent-based models, SR emphasizes the flexibility of the term, stating that agents can represent anything, not limited to humans. In the context of life cycle analysis, vehicles serve as agents, evolving over time. Some agents may exhibit learning or evolving behaviour due to external factors.

SR addresses the potential confusion in terminology, distinguishing between activities and purposes (although trip purpose can be equivalent to activity type a person will do after reaching the trip destination), and individuals and agents. She confirms that households, including their units, can be considered agents, for instance in the context of energy consumption analysis.

SR views activity-based models as transport-demand models, distinct from traffic-assignment models. She explains that agents, such as drivers and passengers, contribute decisions to the metrics used as inputs. The integration challenges between origin-destination (OD) and assignment components in agent-based models are acknowledged, highlighting the complexity of achieving seamless integration.

Population synthesis as an agent-based component
Population synthesis is identified as a central component of activity-based models, functioning as an agent-based model, especially when considering dynamic synthetic populations. SR notes that this approach allows for tracking individuals and households over time, enabling the exploration of future social demographic profiles taking path dependency of life events into account.

Activity scheduling and optimization
SR draws a distinction between activity-only scheduling and activity-based models. While the former involves optimizing the daily schedule with known activities, the latter generates activities as part of the model. Activity scheduling, closer to agent-based models, is compared to optimizing daily schedules based on predefined activities.

Updating ALBATROSS

ALBATROSS model overview

SR provides insights into the ALBATROSS model, discussing its structure of 27 decision trees based on decision-making sequences. Electric charging activities were also incorporated into the model, treated as decision trees because currently charging a vehicle can consume substantial amount of time and thus deserves a dedicate decision tree within the model. The model was extended to identify optimal locations for new charging stations in Eindhoven, demonstrating its adaptability for various applications.

Expanding ALBATROSS for MaaS scenarios

Recent work involves using ALBATROSS to assess how Mobility as a Service (MaaS) adoption impacts emissions in Amsterdam. SR and a student explored scenarios with different MaaS mobility types, from customized to basic. The ongoing research aims to enhance the model's complexity by tripling the levels of mode choices and separating access/egress modes from the main mode, reflecting the evolving challenges of increasing multimodality.

Integration challenges and resource constraints

SR acknowledges challenges in integrating decision trees related to working from home, online shopping, and additional activities. Computational burden, data management, and the need for resource budgets are recognized hurdles. The discussion highlights the academic nature of ALBATROSS, dating back to 2000, and the need for a collaborative effort with commercial companies to sustain and integrate innovative components effectively.

Creating collaborative coalitions

To make ALBATROSS operational, SR proposes collaboration with a commercial company, emphasizing a coalition approach involving resources for PhDs and postdocs. Drawing parallels with collaboration in the national freight model development, SR suggests creating a team that continuously integrates innovative components into the system to maintain its relevance.

Bridging the gap between academic research and practice

SR dismisses the gap between academic research and practice, citing her practical experience and noting that scenario analyses, important for practitioners, are often not the focus of university research. She suggests that companies, driven by specific questions and interests, play a vital role in conducting scenario analyses and bridging the gap effectively.

Urban Tools Next and unexplored differences

The conversation briefly touches on ‘Urban Tools Next’, a tool SR is aware of but lacks detailed knowledge about. SR expresses curiosity about potential differences and leaves the question open, indicating a willingness to explore and learn more about other tools and approaches in the field.

Data and model techniques

Data challenges and plan B

SR addresses the data limitations faced in implementing upgrades to the ALBATROSS model, particularly in areas such as e-shopping and e-commuting. Due to a lack of data from regular sources, SR introduces a plan B, involving a stated choice experiment designed to understand the extent of online grocery shopping and working from home preferences. The experiment considers various channels, such as in-store, online delivery, and pick-up points, providing valuable insights into the population's preferences.

Population synthesis and model integration

SR explains the process of synthesizing population data, incorporating working from home information, and running ALBATROSS to study the impact of online shopping. She emphasizes the practical challenges of updating decision trees and the need to replace offline shopping with online versions based on choice models. SR acknowledges the limitations imposed by the lack of larger-scale data but highlights the ongoing analysis of collected information to derive meaningful results.

Techniques and machine learning

The discussion elaborates on the use of machine learning techniques, specifically neural networks, for various choice models. SR clarifies that while neural networks are employed for certain purposes, ALBATROSS, being a decision tree-based model, sticks to its framework for activity-based modelling. SR draws a distinction between the decision tree structure of ALBATROSS and the discrete choice models used for specific channels like online grocery shopping.

Challenges in implementing ALBATROSS

The conversation shifts to the challenges one might face in using ALBATROSS, especially for those accustomed to transportation software like OmniTrans, Cube, or Visum, which incorporate different assignment techniques. SR explains the process of obtaining OD data from ALBATROSS and the reluctance of consultants and government agencies to fully integrate it into their existing software. The outdated nature of the current version is acknowledged, and SR envisions a more user-friendly interface for broader accessibility.

Availability and language of ALBATROSS

SR confirms that ALBATROSS can be obtained and run on a personal machine, although the existing version is outdated. She notes that ALBATROSS was initially written in C++ but has transitioned to the GO language. The conversation touches upon the possibility of creating a user-friendly interface, addressing the current lack of ease in making changes. SR emphasizes the adaptability of ALBATROSS in GO, making it more modular and user-friendly, and explains the choice of GO over Python based on the software structure and recommendations from a software engineer.

Language standardization and collaboration

The interview proceeds with a discussion on the choice of programming language and the benefits of standardization within the academic community. SR shares her preference for a larger audience using the same (software and modelling) techniques and programs to foster collaboration and progress. The conversation highlights the importance of shared methodologies in advancing the field and avoiding individualized approaches.

Model Uncertainty and Variability
SR discusses uncertainties in the ALBATROSS model, focusing on input and model uncertainties. During her PhD, she addressed input uncertainty by incorporating empirical data on travel time distribution in Rotterdam. Multiple runs (1,000) were performed to assess the impact of different realizations of probability, revealing that input uncertainty had a marginal impact. However, model uncertainty, stemming from the probabilistic nature of decision trees, had a more significant effect. SR suggests further research to reduce model uncertainty, possibly by improving decision trees.

Reducing stochastic elements
The conversation shifts to concerns raised by agencies regarding the stochastic elements introduced by AcBMs. SR explains that AcBMs, including ALBATROSS, introduce variability due to their stochastic nature. She suggests ways to reduce uncertainty, such as increasing the depth of decision trees and choosing additional conditional variables. However, SR acknowledges the challenge of balancing uncertainty reduction with the risk of overfitting. The discussion highlights the need for careful consideration in refining AcBMs for practical applications.

Applicability and user-friendly interface
JK asks about the suitability of ALBATROSS for different governmental levels. SR suggests that, at its current scale, it is more suitable for national governments. She envisions exploring regional versions for smaller municipalities. The conversation touches on the need for a user-friendly interface to facilitate broader use, emphasizing the importance of shared learning within the modelling community. SR sees potential for collaboration and believes that, with the right interface, AcBMs can be more accessible and applicable across various government levels.

Challenges in updating and accuracy
SR addresses the challenges in updating ALBATROSS, including the need for a permanent team member due to the model's complexity. External validation hasn't been pursued extensively due to resource constraints, but SR emphasizes the necessity of continually updating inputs such as road networks and land use. The conversation touches on the time and expertise required for external validation and how the lack of funds and permanent staff hinders this process.

Moving towards activity-based modelling

User-friendly interfaces and community collaboration
The interview proceeds with a discussion about transitioning from traditional to activity-based modelling. SR suggests that a user-friendly interface is important to bridge the gap between academic understanding and practical application. The conversation touches on the need for training, courses, and a shared understanding within the modelling community. SR emphasizes the importance of signalling to students what they need to learn and the significance of a community-wide effort to promote activity-based modelling, especially in Europe.

Population synthesis with neural networks
SR explains that she is conducting a study which used CBS micro data and apply dynamic neural network for dynamic synthetic population in the Netherlands. SR emphasizes that this can replace the current IPF module in Albatross. The dynamic neural network incorporates life events, such as childbirth, divorce, and changes in residence or workplace. This approach allows for scenario testing, considering lag effects for events like having a baby or buying a house. SR notes that decisions at the household level and individual decisions, like car choices, are addressed within the neural network, offering a more dimensional and individual-focused method compared to IPF.

Challenges and organizational considerations
The discussion touches on challenges in implementing population synthesis, including funding and organizational aspects. SR acknowledges the importance of an innovative approach to overcome data-related challenges, considering the rich data available in the Netherlands. Organizational discussions between ministries, universities, and private entities are seen as important. SR emphasizes the need for serious collaboration to navigate legal aspects and transition from traditional models to newer methodologies, such as AcBMs.

Complexity and future directions
JK prompts SR to discuss the future of AcBMs, addressing whether models are becoming more complex without necessarily yielding better decisions or policies. SR highlights the uniqueness of AcBMs. She suggests the creation of a collaborative lab for travel demand forecasting models, akin to the open-source and data-sharing practices in the deep learning community. This collaborative effort could provide insights into the necessity and effectiveness of various models for different policy purposes.

Time constraints
SR expresses enthusiasm for the idea of a collaborative lab and data-sharing initiative. However, she acknowledges time constraints and the need for high motivation from different parties to bridge the gap between academia and practical implementation. The interview concludes with SR proposing a collaborative lab as a potential solution to address the diversity of AcBMs and their impact on policymaking.

Further reading

Labee, P., Rasouli, S., and Liao, F. (2022). "The implications of Mobility as a Service for urban emissions." Transportation Research. Part D: Transport and Environment 102 (2022) 103128.

Keywords: MaaS; Activity-based model; Emissions; Stated adaptation choice

The article examines the impact of Mobility as a Service (MaaS) on urban emissions. MaaS, a user-centric approach offering multi-modal mobility services, aims to mitigate negative externalities in the mobility sector by encouraging the use of various transportation modes instead of private vehicles. The study assesses MaaS adoption and the utilization of different modes within MaaS bundles, using empirical data from experiments and an activity-based travel demand model, Albatross. This model simulates activity-travel patterns in Amsterdam, Netherlands. The findings reveal that *different MaaS scenarios—conservative, balanced, and optimistic—can reduce emission levels by 3–4%, 14–19%, and 43–54% respectively. The degree of MaaS adoption depends on its attractiveness and socio-demographics, influenced by various factors such as service characteristics, pricing schemes, and social influence. The study creates three scenarios based on these factors to evaluate the environmental impact of MaaS under different levels of service attractiveness.*

5.22 Alex Bettinardi

Alex Bettinardi is employed at the Oregon Department of Transportation.

Introduction to the collaboration

In this interview, AB, a representative from the Oregon Department of Transportation, and JK, discuss the collaborative efforts of various governmental agencies in the Netherlands. These agencies are contemplating a shift from their existing trip-based or tour-based models to activity-based or agent-based models. The motivation behind this transition is the inadequacy of their current models in assessing the impacts of emerging systems like micro-mobility, smart mobility, car-sharing, e-commute, and e-commute. The collaboration, known as SIVMO, involves 10 governmental agencies, encompassing statewide, provincial, and municipal levels.

AB's perspective and Oregon's model
AB, situated in Oregon, elucidates the structure and functionality of their transportation modelling at the Oregon Department of Transportation. Covering various metropolitan areas, including smaller and sub-metropolitan regions, AB mentions their current reliance on trip-based models. Notably, they have successfully implemented an Activity-Based Model (ABM) for their state, catering to both smaller and larger metropolitan areas. AB emphasizes the significance of collaboration in Oregon, particularly in terms of surveying efforts, to achieve cost savings and foster a shared foundation for modelling activities.

Common goals and collaboration beyond surveys
AB further discusses the common goals and collaborative initiatives beyond surveys in Oregon. While the survey serves as a pivotal reason for agencies to come together, AB underscores the importance of collective efforts in areas like freight modelling, health representation in models, and addressing greenhouse gas emissions. The interview sheds light on ongoing projects related to accommodating e-commerce and incorporating diverse activities like loop trips, exercise trips, and dog walking into the Activity-Based Model. The common data platform allows for shared research, common estimation, and mutual development of transportation models across different regions.

Survey tradition and modelling challenges
JK highlights the long-standing tradition of household surveys in the Netherlands, undertaken for approximately 45 years. However, this tradition, while beneficial in providing ample data, also led to a fragmentation of efforts. As everyone had access to the statewide or countrywide survey data, individual model developers started building their own models independently. This lack of coordination resulted in a plethora of transport models in the Netherlands without substantial interconnections. AB contrasts this with the situation in Oregon, where the need for collaboration has arisen due to reduced funding, emphasizing that scarcity has brought them together for joint estimation.

Similarity in modelling techniques
The discussion shifts to the modelling techniques employed by different agencies. AB acknowledges that while there have been instances where each agency created its

own branch, currently, Oregon's modelling agencies are becoming increasingly similar. Despite minor deviations, they share a common starting point, and the goal is to align their models to the extent that they could be almost identical across all of Oregon. The emphasis is on pooling resources and creating a more cohesive modelling approach, driven partly by financial constraints and the necessity to work collectively.

Defining activity-based models

AB discusses the definition of activity-based models, particularly in the context of their upcoming estimation series in 2024. While still in the process of implementing these models, AB notes that their approach shares similarities with agent-based models. The activity-based models track individuals but may not delve into a full microsimulation of minute-by-minute decision-making. AB clarifies that although there is person tracking, the model doesn't represent every instant of a person's positioning and decision-making in exhaustive detail. This prompts an acknowledgment of the ongoing debate about how to precisely define activity-based models, especially in the current landscape where the term "agent-based model" is sometimes applied broadly, even when not entirely accurate.

Understanding agents in models

Defining agents

AB begins by sharing his understanding of agents in models. He likens agent-based models to scenarios involving evacuations for natural disasters, such as tsunamis or forest fires. In these models, agents make second-by-second decisions, influencing their positioning and evacuation routes. AB emphasizes the high-resolution temporal tracking in agent-based models, distinguishing them from activity-based models like the one Oregon uses. While activity-based models lack such temporal tracking, they provide detailed representations of individual attributes and their impact on decision-making throughout the day. AB suggests that, in his view, activity-based models are not equivalent to agent-based models, aligning activity-based models more with macro assignment than microsimulation.

Oregon's transition to activity-based modelling

AB provides a historical perspective on Oregon's approach to transport demand models. The statewide model was primarily tour-based until around 2014 when the need to address greenhouse gas (GHG) impacts, vehicle technologies, and emerging trends like micro-mobility prompted a shift towards activity-based modelling. Oregon initiated a separate research and development process to bring an Activity-Based Model (ABM) in-house for one of the metropolitan areas. This AcBM, borrowed from California, was recalibrated for Oregon and successfully implemented for the southern region. AB highlights the lessons learned from this experience and the intention to deploy AcBMs more widely, especially with the upcoming survey in 2024.

Survey focus and decision-making process

The discussion then turns to the upcoming survey, which will be geared towards activity-based models and include questions on activities at home. AB explains that the survey aims to capture people's comfort and willingness to bike, reflecting a collective effort to understand decision-making processes related to biking. AB notes that Oregon moved away from trip-based models in 2013-2014, primarily driven by the desire to better represent GHG impacts. The decision was influenced by the recognition that a trip-based model, while more affordable in the short term, wouldn't provide the long-term benefits and precision offered by an activity-based model, especially considering Oregon's strong goals and targets related to GHG reduction.

Cost considerations and policy objectives
AB highlights the cost considerations involved in the decision-making process. While transitioning to an activity-based model was slightly more expensive, it was deemed a worthwhile investment compared to updating and maintaining an aging trip-based model. AB also mentions that policy objectives, particularly the focus on GHG reduction, were significant drivers for adopting activity-based modelling. The decision was strategic, considering the long-term benefits, such as better representation of evolving transportation technologies, improved health representation, and the ability to capture future developments more accurately.

Model limitations and design challenges
AB reflects on the implementation of activity-based models, acknowledging that initial expectations were somewhat optimistic. The transition from trip-based to activity-based models brought to light the need for meticulous model design. Despite tracking individuals, certain aspects, such as expenditure details on public transit or tolls, were not automatically recorded by the model. This realization underscored the importance of comprehensive design to capture all necessary data accurately. The ongoing model design phase aims to address these limitations and emphasizes the need for thoughtful consideration beyond merely adopting a new model structure.

Learning curve and metric challenges
Implementing activity-based models presented a learning curve for the modelling team. Shifting from trip-based models to activity-based ones required adjustments in approach and mindset. AB highlights challenges in metrics, particularly in reporting vehicle miles travelled (VMT). The increased disaggregation in activity-based models introduced new ways to analyse VMT, considering demographics and non-home-based factors. Additionally, representing intersection congestion in a more defined manner required a rethinking of how data is shared and discussed. These shifts in metrics and data representation posed unanticipated challenges, emphasizing the importance of adjusting procedural sequences and effectively communicating changes to users accustomed to the previous model structure.

Communication and documentation evolution
The discussion discusses the evolution of communication and documentation practices. AB describes a transition from lengthy, detailed PDF documents to a more concise and accessible Wiki format. The Wiki, embedded within the code repository on GitHub, serves as a user-friendly platform for sharing information. This shift not only facilitates ease of access but also enables quick updates and additions to the documentation, enhancing its relevance. The move to a simpler, one-page instructional format with an interactive table of contents aids in digestibility and keeps information current. The emphasis on this communication evolution highlights the need to adapt documentation strategies to align with user expectations and facilitate efficient knowledge transfer.

Comparison of documentation platforms

AB and JK discuss the choice of GitHub for documentation, noting its advantages, such as public accessibility and integration with the code repository. However, JK expresses reservations about GitLab's usability in the Netherlands, favouring the integration of source code and documentation within one system. This prompts AB to share examples from GitHub, illustrating the linkage between documentation and the code repository. The conversation touches on the importance of transparency, accessibility, and ease of navigation in documentation platforms, with different preferences emerging based on individual experiences and organizational needs.

Reception and internal challenges

AB provides insights into how the transition to activity-based models was received within the organization. The management's response was generally positive, facilitated by specific conditions set by higher-level authorities, aligning with the governor's directives. This made it easier to justify the shift despite some increased costs. However, AB emphasizes that the more significant challenge was the internal adjustment to the new modelling approach. The shift from trip-based familiarity to activity-based models required overcoming a learning curve and a mental shift, disrupting established procedures.

Model output and policy initiatives

The conversation shifts to the output of the activity-based model, specifically the transition from the model to assignments. AB explains that this process involves creating an origin-destination (OD) matrix. The product of the activity-based model is a matrix that serves as input for further assignment processes. AB highlights that despite the sophistication of activity-based models, the assignment process still involves aggregating data into a simple OD matrix. This reveals that, despite the advanced modelling techniques, certain simplifications are made for practicality and speed in the assignment phase.

Effectiveness in policy decisions

The discussion then discusses the effectiveness of the activity-based model in influencing policy decisions. AB candidly acknowledges that initial expectations of magically improved policy outcomes were not met. The model's deployment did not automatically lead to better representation of active modes like biking and walking. AB clarifies that a more nuanced setup is required, including the design and formulation of the model to accurately capture and represent the desired outcomes. AB provides an example of the ongoing work to incorporate attitudes towards biking to enhance the quality representation in the model.

Comparisons between models

AB reveals that comparisons between the trip-based and activity-based models were conducted. While acknowledging the challenges in directly comparing the two models, AB indicates that they observed differences but were able to explain and justify them. The absence of any unexplainable or irrational results provided confidence in the transition. This emphasizes the importance of understanding and adapting to the subtle variations between models rather than expecting identical outputs.

Advice for transitioning

AB offers advice for those contemplating a similar transition. AB suggests starting with a demo test case, allowing one region or group to experiment with the new model, fostering familiarity and comfort. The importance of having a positive and willing mindset within the group is highlighted. AB also discusses the phased approach taken by Oregon, testing initially with one region and gradually rolling out the new framework to others. The multi-year rollout is designed to accommodate each region's unique cycle, ensuring a smoother transition without imposing an abrupt shift on all model regions simultaneously. This strategic approach is recommended to validate the new model's suitability before widespread adoption.

Public documentation and procedures

AB discusses the availability of public documentation beyond wikis. When asked about how the team collaborates and the procedures they follow, AB mentions that there is some information about their work on public websites. However, AB acknowledges that it may not cover all aspects of their procedures. Regular meetings are highlighted, both among Oregon partners and investors, as well as consultant-led design meetings. These logistical processes, essential for keeping the project on track, are not extensively documented online but play a crucial role in the organization's functioning.

Collaboration with consultants

The conversation shifts to the collaboration with consultants. AB explains that consultants are hired for activity code development, with a transition from a single consultant to contracting with three major firms RSG, WSP, and Cambridge Systematics. These firms conduct weekly code development on activity SIM, ensuring familiarity across different regions in the United States. AB discusses the approach adopted by Oregon, following a similar pattern, contracting with the same three firms for the Oregon estimation. The collaborative effort involves coordinating design phases, and AB highlights the expectation of sharing the workload during estimation and calibration phases across different regions and firms.

Competition and collaboration among consultants

AB is asked about the dynamics between consultants, whether they compete or work together. AB explains that it's a combination of both. While there is some competition for individual pieces of work released under the umbrella contract, there is also a collaborative aspect. The firms have formed partnerships, and there is an understanding that the workload will be shared. AB emphasizes the advantages of having a pool of resources from different firms, contributing to the overall success of the project.

Involvement of universities or academics

When asked about the involvement of universities or academics, AB acknowledges the idea but notes that direct involvement has had mixed success. Research endeavours, especially those related to e-commerce and loop trips, are mentioned as university research functions. These functions are seen as secondary and more aligned with research than being directly applied under the contract. AB clarifies that while universities are involved, it's often through side contracts for more research-oriented tasks.

5.23 Nila Sari

Nila Sari is Principal Transport Modeller at the Department for Transport (DfT) UK.

Terminology

Understanding transport models: activity-based vs. agent-based
In this interview, NS shares her insights on activity-based models and agent-based models from a transport modeler's perspective. The discussion begins with the challenges of distinguishing between them, highlighting the confusion in terminology, especially when both are abbreviated as ABM. NS explains the Transport Analysis Guidance (TAG) and its role in providing standards for transport modelling, emphasizing that flexibility exists for innovating and using different methodologies.

Navigating the confusion: AcBM vs. AgBM
NS discusses the common confusion surrounding agent-based and activity-based modelling, acknowledging the difficulty in defining and differentiating the two. She stresses that the Department of Transport does not impose rigidity but requires a thorough understanding before accepting a model for appraisal. NS describes ongoing efforts to create guidance for AABMs, acknowledging the challenge of establishing a common understanding within the industry.

Defining activity- and agent-based: A work in progress
The interview moves on to NS's attempt to define agent-based modelling (AgBM) and activity-based modelling (AcBM) clearly. She acknowledges the confusion caused using these terms and the need for a unified understanding. NS highlights that Agent-based involves agent-agent interactions, while Activity-based can be implemented using an agent-based method. She mentions the unique challenges faced by those developing AABMs, especially with the varying interpretations of the models.

Debating terminology: agent-based or activity-based?
The discussion takes a turn towards debating the terminology, with JK suggesting that using the term "agent-based" may simplify understanding. NS, while open to the idea, expresses concern about potential resistance from others in the industry. The interviewee acknowledges that the department is working on a guidance unit for both AcBM and ABgM, but the jury is still out on whether simplifying the terminology will resolve the confusion.

Transport Analysis Guidance (TAG)

Building TAG: organizational structure and collaboration with consultants
NS provides an overview of the Transport Analysis Guidance (TAG) and its organizational structure within the Department of Transport. TAG is comprised of various guidance units catering to different stakeholders, including project managers, senior responsible officers, appraisal practitioners, and modelling practitioners. The interviewee emphasizes the importance of collaboration with consultants in developing and updating TAG, acknowledging their expertise in hands-on model development.

TAG's evolution and collaborative process
NS traces TAG's history, mentioning its development over the past 20 years. She highlights the collaborative process with consultants, the recent prioritization of specific units for update, and the ongoing peer review of the draft. NS acknowledges the challenges faced by her small team, especially with recent resource constraints due to a team member leaving.

The role of the Governance Board
NS explains the role of the internal Governance Board, consisting of experts within the Department of Transport. The board oversees any changes or developments in TAG, ensuring that proposed updates align with departmental policies and standards. She distinguishes this internal board from the Joint Analysis Development Panel, an external group that advises on various aspects of modelling and appraisal.

Frequency and policy alignment of TAG updates
The discussion touches on the frequency of TAG updates, which may occur at least twice a year, with potential changes to reflect latest evidence and best practice. NS emphasizes the need for consistency in publication timing (May or November) to prevent confusion among users. The conversation also underscores the alignment of TAG with government policies, providing stability for users preparing business cases.

TAG's application at different government levels
NS clarifies that TAG is not mandatory but highly encouraged, especially at the local level. Local governments using TAG for appraisals seeking funding from the central government find it beneficial. NS notes that TAG is widely adopted within the transport community, even beyond mandatory use cases, as it serves as a valuable tool for policy testing.

Exploring European Guidelines and external TAG variations
The interview touches on the existence of European guidelines like TAG. NS expresses familiarity with the Australian version but seeks information on the European Commission's guidelines. The conversation concludes with NS suggesting raising another question for further exploration.

Exploring agent-based models: Status and challenges

NS discusses the department's current position regarding AgBM and AcBM. Although the department does not possess a model of its own, NS mentions a past collaboration with consultants from Connected Places Catapult to develop an AcBM focused on exploring Mobility as a Service (MaaS). However, the department does not own the model, limiting further development. NS acknowledges the challenges of not having direct control over the model's evolution and the need for research into potential methodologies.

Resistance and research for activity-based modelling
NS highlights challenges faced when exploring activity-based modelling within the department. She expresses the importance of moving forward but emphasizes the need for research before undertaking such a significant shift. The interview touches on the reluctance of some experts to immediately adopt new methodologies due to limited knowledge and potential financial implications. NS stresses the importance of

thorough research, citing the ongoing efforts to explore activity-based modelling as a research area.

Balancing prescriptiveness and innovation in modelling
The conversation discusses perceptions of TAG potentially limiting innovation. NS clarifies that TAG aims to provide guidance while allowing for methodological innovation. She discusses the balance between offering step-by-step methodologies to aid practitioners and avoiding undue prescription that hinders innovation. NS emphasizes the department's openness to new methods and encourages practitioners to engage in dialogue about innovative approaches. The interview reflects on historical instances of resistance to model transitions and draws parallels to the current challenges faced in adopting new methodologies.

TAG's role in European Commission Guidelines
The interview briefly touches on the European Commission's guidelines and better regulation tools. JK mentions the November 2021 regulations and guidelines used for assessing policy measures at the European Commission level. He expresses willingness to share relevant materials and provides a link to further resources. The conversation highlights the practical aspects of using these guidelines in policy assessment.

Addressing resistance and encouraging innovation in modelling
The discussion concludes with NS addressing concerns about TAG limiting innovation. She emphasizes the department's willingness to embrace new methods, encouraging practitioners to communicate and propose innovative approaches. The interview sheds light on the delicate balance between providing guidance and fostering an environment that allows for creativity and advancements in transport modelling methodologies.

Data

TAG's approach to data collection recommendations
In this segment, NS provides insights into TAG's stance on data collection. Acknowledging the fundamental role of data in model development, NS confirms that TAG does offer recommendations on data for models. She mentions a dedicated unit within TAG that focuses on data sources and surveys. However, NS clarifies that the guidance avoids detailed instructions on survey methodologies, citing past overlapping with guidance from national highways, which was eventually withdrawn. TAG provides information on the types of data required for certain models, such as demand models, including options like census data or mobile phone data.

Balancing data guidance and avoiding prescriptiveness
NS further explains TAG's approach to data guidance, emphasizing the avoidance of excessive detail. While TAG points out available data types, it refrains from specifying survey details, sample rates, or precise requirements for certain data sources. NS mentions the intention to provide information to assist without overwhelming practitioners, emphasizing principles, and suggesting potential data sources. The conversation touches on the balance between offering guidance and avoiding excessive prescription, promoting flexibility in data collection approaches.

Privacy and Ethical Considerations in Data Usage
Addressing privacy and ethical concerns related to data, NS notes that privacy becomes a significant issue when dealing with highly detailed data, such as sensor data. She suggests that, in many cases, the data used for transport models is already available without identifying individuals. This brief section highlights the awareness and consideration of privacy issues in the context of data collection for transport modelling.

Cooperation

Consultant pool and collaborations for TAG updates
The conversation shifts to the topic of updating TAG, with JK proposing the idea of creating a pool of consultants and academic experts for more regular collaboration. NS expresses the appeal of such a setup but notes budget constraints and the need to make a case for updating guidance. While the current process involves periodic updates with consultant involvement, NS acknowledges the potential benefits of a more regular collaboration and a diverse pool of experts. The dialogue highlights the importance of ongoing collaboration for the evolution of TAG.

Advice on collaborative approaches
JK seeks advice on collaboration strategies between different governmental agencies, mentioning a successful experiment in the Netherlands involving a pool of software engineers and transport modelers. NS commends the collaboration but acknowledges the challenges, particularly budget-related constraints. She suggests a stepwise approach and encourages a focus on data initially. NS also shares the experience of developing a national trip-end model and how it evolved to serve multiple sectors beyond transport modelling. The Department was embarking on the development of a national synthetic population. The conversation provides insights into the challenges and benefits of collaborative efforts in the realm of transport modelling.

Challenges

Guidance on uncertainty in TAG
NS discusses the topic of uncertainty within TAG, acknowledging a dedicated unit that manages guidance on uncertainty and forecasting. Interestingly, this unit is distinct from others within TAG. NS highlights the existence of an uncertainty toolkit aimed at assisting practitioners in exploring uncertainty within their models. Additionally, she mentions the creation of common analytical scenarios, involving seven different scenarios. These scenarios aim to test the robustness of business cases under various conditions, addressing uncertainties and providing a comprehensive evaluation framework.

Navigating stochasticity in models and real-world uncertainties
The discussion extends to the distinction between uncertainties inherent in transport modelling and uncertainties in the real world. The mention of stochastics prompts a conversation about the acceptance of stochasticity in models. JK poses a thought-provoking question, suggesting the adoption of stochasticity as an inherent aspect of modelling. NS expresses the importance of maintaining equilibrium in the model, acknowledging potential resistance to a shift in perspective. The conversation

explores the challenges of disentangling model-induced changes from real-world stochastic influences.

Challenges in assessing model output and secondary use cases
JK brings up challenges in assessing model outputs, especially concerning secondary use cases like emissions calculations. NS aligns with these concerns, noting the potential issues with using model outputs to calculate benefits such as user benefits and emissions. She acknowledges the existing questions and concerns that hinder immediate adoption of new modelling methods, emphasizing the need for ongoing evaluation and addressing these uncertainties.

TAG's approach to training and engagement
The conversation transitions to the training aspect of TAG. NS clarifies that while there is no formal training programme, TAG has engaged with practitioners through workshops and conferences to explain specific parts of TAG. The emphasis is on making TAG available and encouraging users to explore and learn independently. NS highlights the openness to questions, signalling a collaborative approach to support users who seek clarification or guidance.

Overlapping models and regional collaboration
The dialogue explores the issue of overlapping models in different regions. NS discusses how local models may overlap with each other and the national model. However, she mentions there are no specific protocols or regulations to ensure consistency across overlapping areas. The conversation touches upon potential conflicts arising from differing results between models in overlapping regions. NS notes that the primary focus is on validating and calibrating models based on available data rather than enforcing standardisation.

Further information

NS shared guidance on agent-based methods and activity-based modelling in TAG: [TAG unit M5-4 agent-based methods and activity-based demand modelling - GOV.UK (www.gov.uk)](). It is intended to be an introduction to these models so practitioners can explore. The guidance will evolve once more experience has been gained about these modelling methods.

Annex 6 Findings from the workshop

SIVMO has several questions that require answers and validation. How to define activity- and agent-based models? How long does it take to build an AcBM? What challenges do we see for model maintenance? What policy questions can an AcBM answer? In a workshop these questions were addressed.

6.1 Introduction

On behalf of SIVMO, an international workshop was held on 2 February 2024 in Leiden, the Netherlands, attended by an audience of 12 attendants (see list next section). The core objective of the workshop was to have a dialogue concerning different questions on activity- and agent-based models (AABMs). This workshop is part of an inventory into AABMs about the whether these models should be introduced in the Netherlands.

The format of the workshop was designed to explore each theme. The participants were introduced to the theme with questions through a brief presentation, outlining the key issues for subsequent discussion. The table on the next page provides a summary of the questions and topics covered during the workshop, ranging from the clarification of terminology in modelling to the practicalities of model maintenance and the applicability of models in answering contemporary policy questions.

6.2 Attendants

In alphabetical order the following people attended the workshop:
- Daniel Berthelsen (Municipality of Copenhagen, DA)
- Frank Hofman (Rijkswaterstaat, NL)
- Mirco Hogetoorn (Panteia, NL, notes)
- Anne Jousma (Gemeente Utrecht, NL)
- Jos Kalfsbeek (SIVMO, NL)
- Jan Kiel (Panteia, NL)
- Marits Pieters (Gemeente Amsterdam, NL)
- Nila Sari (Department for Transport, UK)
- Wolfgang Scherr (Moventes, CH)
- Maaike Snelder (TNO, NL)
- Amand Stevens (Provincie Noord-Brabant, NL)
- Collins Teye (Transport for London, UK)

Tabel 1 Themes and questions of the workshop

Theme	Questions/Topics
Method	Clearing up terminology of activity-based and agent-based models
	Transition from trip- or tour-based models to activity-based models
	Geographical scope for which the activity-based model is best suited
	Stochasticity of modelling results, how to deal with it?
Process	How long will it take to build an activity-based model?
	What do we need to do over the next 12 months?
	How do we engage the market and other stakeholders?
Maintenance	What challenges do we come across in maintenance of the model systems?
	Who owns the models?
Application	Can traditional models provide sufficient answers to policy questions?
	What questions can be answered with an activity-based model?
	What are the emerging policy questions?

6.3 Definitions and methods

6.2.1 Definitions

The definition of activity-based models (ABMs) and agent-based models (ABMs) have become ambiguous over time. The presenter points to the evolution of ABMs since the 1990s and presents a table distinguishing between trip-based, tour-based, microsimulation, activity-based and agent-based models.

The discussion turns to the definition of activity-based models and agent-based models and points out the confusion surrounding these terms. Activity-based models can be clearly defined and comprise models such as a population synthesis and an activity scheduler. The main question is whether agent-based models can be clearly defined. The discussion on this question also covers the role of self-learning parameters in these models, as the in the strict definition of agent-based models, these models are self-learning (which is different than running multiple iterations).

Participants have different opinions on the definition and necessity of 'self-learning' in agent-based models. There is an acknowledgement of the confusion caused by the term "agent". It is suggested to be specific about the components of the models, such as population synthesis or activity schedulers. While it may not be necessary to have strict definitions for activity-based models and agent-based models, clarity is essential when specifying the requirements and components of the models. The importance of avoiding confusion and clearly articulating model expectations is stressed, and to emphasise the underlying components such as a population synthesis.

Concluding, the term "agent-based" is an umbrella term and should be avoided whenever possible and instead name the underlying model(s) clearly. However, doing so might prove challenging as it has settled as a used term in the larger modelling community.

6.2.2 Model transition

The discussion on model transition in activity- and agent-based models (AABMs) revolves around the possible integration of activity-based models with existing trip- or tour-based models. Participants explore the idea of a gradual transition from traditional models to activity-based models, considering components such as population synthesisers.

A key point raised is the importance of retaining the ability to model individuals end-to-end in AABMs, which distinguishes them from tour- or trip-based models. The population synthesiser is highlighted as a valuable component because of its flexibility in adding population segments and improving the adaptability of the model. It allows the creation of diverse populations and facilitates collaboration between different organisations. The participants discuss the experience of transitioning from existing models to activity-based models. Examples from both Copenhagen and Switzerland show an incremental approach, replacing components or upgrading parts of the model while retaining certain elements. .

The benefits of modular development, such as process efficiency, maintenance benefits and cost efficiency, are recognised. The potential for data sharing and consistency between different models (such as urban, regional, and national models) is also discussed as an important benefit, especially in collaborative efforts between entities such as the railways and the national government in Switzerland.

Concluding, a collaborative modular development in AABMs is recommended. It is feasible and offers advantages in both methodological and practical aspects.

6.2.3 Geographic scope

The discussion on geographical scope revolves around the different levels at which these models can be applied, such as urban, regional, or national level. Different perspectives are presented, with some arguing for a focus on the urban level because of the mobility challenges within cities or at a regional level, while others argue for an application at the national level to address broader behavioural questions. The debate centres on whether geographical scope matters and whether there is an ideal level for AABMs.

The consensus leans towards the view that the geographical scope does not necessarily matter and emphasises the potential of AABMs to generate activity for whole populations. The main bottleneck is rather computational time, but advances in computing technologies are seen as promising to overcome this limitation. However, the challenge lies in determining the right cut-off point, especially when it comes to international travel and the need for solutions across administrative borders.

Participants discuss their experiences, including the preference for a single comprehensive model that addresses all policy questions for a specific region. Flexibility in model design, sampling and the use of new technologies are mentioned as ways to reduce computation times and make AABMs more versatile.

The conversation also covers the importance of the practicalities of defining a study area, drawing parallels with travel-based models. Some participants suggest starting with a smaller, more manageable pilot area for experimentation before starting on a larger scale. The discussion highlights the complexity of striking a balance between geographical scope, computational efficiency and the depth of behavioural questions addressed by AABMs in the context of urban and regional planning.

Concluding, the geographical level does not necessarily matter for the development or application of an AABM. Rather, the size of an area could be a bottleneck for computing time.

6.2.4 Stochasticity

The discussion on stochasticity revolves around the challenges and considerations regarding the inherent variability in model simulation runs. In the Netherlands, there is a legal requirement for models to be reproducible for five years, but stochasticity introduces variability between simulation runs. Workshop participants share their approaches to address this problem.

There are different perspectives on how to deal with stochasticity, ranging from accepting variability or use of seeds, to running multiple model simulations and taking the averages. Some participants suggest accepting variability as a natural aspect of simulations. The use of seeds, which determine the initial conditions of a simulation, is discussed as a common practice. Participants note that seeds are important for calibrating models, ensuring consistency between model runs and maintaining reproducibility.

The distinction between random numbers and seeds is explained, stressing the importance of consistency in the distribution of random draws for accurate simulations. Random numbers, despite being termed "random," are generated through deterministic processes by algorithms, making them pseudo-random. This means that while the numbers appear random for practical purposes, their sequence is entirely predictable if the starting point, or "seed," is known. The seed is a specific initial value fed into the random number generating algorithm. By setting a seed, one essentially anchors the sequence of pseudo-random numbers generated, ensuring reproducibility of the simulation results.

The discussion addresses technical aspects of using seeds, such as whether the seeds for the base year should be the same as those for future years, given population changes. The underlying concern is that any change in the seed for random numbers could lead to variations in the distribution of random draws, which might not accurately reflect the intended stochasticity across different simulation scenarios.

Further concerns are raised about the potential drawbacks of using seeds, leading to a discussion on the need for multiple runs to account for variability and the challenges of freezing error terms in choice models over time. Participants stress the importance of considering the level of aggregation and nature of policy questions when determining the number of model simulation runs needed for reliable results.

The workshop participants also address the practical implications of stochasticity in AABMs, especially when it comes to regional and urban-level scenarios. The issue of transparency is raised, emphasising the importance of informing stakeholders about variability in model outcomes.

Concluding, it is recognised that accepting stochasticity is important for innovation in modelling, despite the challenges it poses for stakeholders who rely on models for policy decisions and business cases with reproducible results. The need for a balance between innovation and stakeholder comfort is recognised, with the understanding that continuous learning and improvement are integral to the modelling process. The use of seeds is recommended for reproducible results.

6.4 Process and organisation

6.3.1 Time taken to build an AABM

In this part of the workshop, participants discuss the time required to build a fully functional AABM model. The model in question is described as a population synthesis/activity diagram-based model.

Participants could choose from five options regarding the time frame for building the model. One to three years was the most popular options. Most participants chose this option with the development of the AABM in mind. In Copenhagen, the AABM model was made public in 2019 and handed over in 2021. However, the preparation used already existing research and models, thus shortening the actual timeframe for developing the model.

The discussion expands on challenges and considerations in the AABM model building process. Issues such as data collection, stakeholder engagement and the procurement process are covered. The importance of understanding the kinds of questions the model needs to answer and the challenges involved in modelling unconventional scenarios is highlighted.

Other participants provide insight into the planning and procurement phases, suggesting that the whole process can take at least 3 years, when including preparation and procurement. The presenter points out that building the model can involve more than just technical development, but also administrative preparations, which can increase the time frame to three to five years.

Experiences from Switzerland and Denmark are shared, highlighting factors such as agile processes, minimum viable products, and the challenge of writing comprehensive requirements. The importance of separating the construction process from the assignment of the model is discussed, recognising the complexity of agreeing on inputs in multi-regional models.

Concluding, the discussion highlights the multifaceted nature of building AABM models, involving technical, administrative, and planning considerations. The different perspectives suggest that the time frame may vary, depending on factors such as existing resources, procurement processes and the level of innovation required in the model. Three to five years seems plausible when considering the entire process.

6.3.2 What to do in the coming year?

The discussion in this section is about planning for the next year in the context of activity models. The central question here is, "What should we do in the coming year?"

One participant suggests doing nothing initially, stressing the need to process and clarify objectives before making decisions. Another participant stresses the importance of reflection, especially in a large company with many questions and answers. There is agreement that, especially when developing an activity model from a partnership, it is important to reflect on what is desired.

The conversation then turns to the practical aspects of model development, focusing on whether you should start by building a population synthesiser or an activity planner. The argument for the latter stems from the belief that defining interactions between entities is the biggest challenge. However, the idea of developing a population synthesiser and an activity planner simultaneously is floated, with the suggestion of creating a roadmap that allows parallel development.

The dialogue extends to discussions about research data, the limitations imposed by available data and the possible need to adjust research questions. Some participants stress the importance of getting a model built quickly and then adding features on top of that base. The option of adapting existing data for initial model development was also considered to speed up model development. The conversation continues with the challenges of involving stakeholders in the development process, as they need to understand the need for the model before they will approve it. For this either training staff to explain better and/or showing what the new model can do that the old one could not were considered.

Concluding, the participants did not conclude, but rather recommended to first start the process and organisation of developing an AABM. Based on this, preparations should be carried out to start developing an AABM, to begin with a population synthesiser.

6.3.3 How to engage the market?

Workshop participants engaged with each other on how to involve the market in the development of AABMs. The conversation covered various aspects, ranging from the ideal scenario of joint ownership and collaboration between government, academics and the market to the challenges associated with technical debt and software sustainability. The example of the national freight model in the Netherlands (BasGoed), developed through a collaboration between the government and the market, showed a successful alliance where the framework contract was drafted by the government. The development and deployment were a joint effort.

The issue of ownership and access to models came up, with some participants advocating an open-source approach, while others discussed the challenges of navigating closed communities or proprietary software. The Dutch experience with a community for modelling showed successful collaborative development within a limited open-access framework. The approach of a collaboration between client, consultants and academics in a semi-open framework seems promising. On one hand due to use the small knowledge base in the Netherlands efficiently, on the other hand due to not to creating a vendor lock-in.

Technical debt, long-term sustainability of models and the risk of dependence on specific consultants or developers were also discussed. Participants explored the importance of clear documentation, code standards and software collaboration platforms such as GitLab or GitHub for sharing and maintaining models. The Swiss perspective emphasised the value of joining larger communities to increase the survivability of models and avoid reinventing existing solutions.

Concluding, the participants recognised the complexity of balancing collaboration, ownership, and technical considerations in developing AABMs. Collaboration between governments, consultants, and academics in a semi-open AABM development and application framework is recommended.

6.5 Maintenance

6.4.1 Challenges in maintenance

The discussion on the challenges of maintaining activity- and agent-based models (AABMs) covers several key topics. Participants share their views on what maintenance entails and highlight the broad spectrum it covers.

Maintenance includes for example keeping network developments up to date, including even changes in signage or bus stop locations. The challenge arises between the base year and future years, especially in the context of changing scenarios such as post-COVID recalibration. The discussion extends to maintenance of software, data, and model versions, with a focus on user support and recalibration based on current services.

Key issues revolve around up-to-date data, further development, consistency, and independence from the market. It is proposed to ensure a national synthetic population that each government agency can use, but the challenge lies in coordinating updates from different stakeholders with different timelines and software packages. Responsibility for maintenance and bug fixing raises questions about who bears the financial burden and how independence from the original developers is maintained.

The conversation turns to the complexity of maintaining software tools, especially if they are written in obsolete programming languages. Dependence on external consultants for expertise becomes a challenge, as the pool of available consultants in the Netherlands is narrow. The idea of making the software open source is discussed, but concerns arise about consistency and correct usage.

The discussion then shifts to the maintenance of models, especially AABMs. Participants share experiences with annual and major updates and stress the need for consistency and synchronised timelines. Challenges in forecasting and scenario differences between urban models and the national model are highlighted. The complexity of AABMs is recognised, leading to a debate on whether they inherently cost more to develop and maintain. While some argue for simplicity, others suggest that costs may decrease as experience is gained and knowledge about AABMs increases.

Concluding, different challenges maintaining AABMs were identified, such as ensuring up-to-date data, annual updates of the models, coordination of updates with different stakeholders, dependency on consultants for expertise, financial responsibilities for maintenance and bug-fixing, maintaining software tools written with obsolete programming languages, open-source software with concerns on consistency and usage, and the complexity of these models. Participants struggle to find a balance between innovation and cost-effectiveness while addressing the unique challenges of AABMs compared to traditional models.

6.4.2 Ownership and maintenance

The discussion on ownership and maintenance of activity- and agent-based models is about who is responsible for maintaining and updating these models. The most important factor is the relationship between development and ownership. In the case presented, the province of Noord-Brabant has limited internal capacity for model development and relies on external consultants for this aspect. However, maintenance of the model is a joint effort, with the consultant responsible for certain maintenance tasks.

The financial aspect is important as it depends on who owns and develops the model. The debate is about whether the government or the market should bear the cost of maintenance. Various funding models are mentioned, such as making users pay for access to the software and using the potentially generated revenue for maintenance. The issue of public funding also comes up, with some arguing against charging users of the model because of its origins in public funding.

The conversation shifts to the challenges of introducing new features into models, especially in the context of changing scenarios such as increased remote working because of COVID-19. There is concern about ensuring consistency and reliability in the model and the model outputs when new elements are added. For this reason, model development in parallel should be considered so old and new model results can be compared, this can also be used as justification for the new model to policymakers.

Concluding, the challenges in maintaining AABMs are not fundamentally different from traditional models. The need for thorough comparisons between old and new models is acknowledged, along with the recognition that innovation and improvements can lead to different results. The importance of maintaining a clear narrative of model improvements is emphasised, even if this initially involves a more complex and time-consuming process. The ownership and costs of the models should be placed and coordinated by the governments.

6.6 Policy and application

6.5.1 Can traditional models provide sufficient answers?

The discussion focused on the application of tour- and trip-based models in answering questions about shared mobility. Participants discussed the challenges of including aspects of trip sharing in tour-based models, especially in assigning people to vehicles. While it was recognised that it is possible to determine the use of shared modes of transport with sufficient data, the consensus was that microsimulation models are more appropriate to address such complexities.

The importance of shared mobility in the overall traffic landscape was discussed, with some participants emphasising its importance from a policy perspective, despite its current low use in the Netherlands. The conversation shifted to the motivations for building activity-based models, with a focus on understanding active mobility and a lack of sufficient data.

The initial hype around autonomous vehicles and future mobility was highlighted. However, the focus on shared mobility decreased when COVID-19 began. It was noted that walkability remains important for egress from public transport.

The discussion continued with a series of statements questioning the practicality of activity-based models in real-world forecasting. Participants expressed scepticism about the ability of current AABMs, both academic and real-world, to make accurate forecasts, especially in scenarios where 'entities' such as persons or vehicles do not know each other. In COMPASS however, the persons in the same households do know each other. Because of this there is a limitation of the usage of a car owned by the household so it can only be used by one person at a time. The limitations of current activity-based models in answering queries like shared mobility were acknowledged.

One participant shared his experience and mentioned explicit simulations in small subsets but expressed doubts about scalability to larger populations due to technical limitations and computation times. The group wondered whether THE framework for building comprehensive activity-based models exists and discussed challenges such as verification, parking issues and memory usage.

Concluding, traditional models provide sufficient answers, but struggle with more complex questions such as on behaviour and shared mobility. The AABMs provide more detailed results to better underpin the answers.

6.5.2 What questions can AABMs answer?

This section focuses on the policy questions that AABMs can answer compared to traditional travel- and tour-based models. The discussion highlights specific scenarios where AABMs prove to be more effective.

First, the limitation of travel- and tour-based models in dealing with road pricing is discussed. An example is given for London, where an area-based pricing system is in place. Traditional models struggle to ensure that individuals pay only once if they make multiple trips, while activity-based models capture the full day of trips, allowing a more accurate assessment of the impact of charges on individuals.

Second, the concept of "analysis of switchable trips" is introduced, with the aim of encouraging car users to switch to public transport. This involves identifying scenarios in which public transport is attractive but underutilised. Activity-based models, which consider entire travel chains, facilitate understanding patterns that can inform policies to promote such shifts.

The third area discussed concerns scenario planning using AABMs, which incorporate population data, land use data and network information. The models allow the generation and simulation of different demographic scenarios and offer insights that are difficult to quantify with traditional methods.

The discussion further extends to other potential applications of AABMs. Emission zones, appearing in various regions, are suggested as a domain where AABMs offer better insights, given their ability to distinguish vehicle types and individual behaviour. In addition, issues such as parking rates, activities from home and health and exposure are proposed as areas where AABMs excel due to their ability to capture detailed information at the individual level.

Participants also discuss the gradual shift towards microscopic detail in AABMs, which provide more precise insights into movements and behaviours of populations. The discussion concludes with reflections on the challenges of convincing management to invest in AABMs, noting that changing management priorities and external factors, such as the COVID-19 pandemic, can affect the perceived benefits of these models. Overall, the workshop highlights the versatility and effectiveness of AABMs in addressing complex policy questions related to transport and urban planning.

Concluding, in this part of the workshop the questions Activity-based models can answer were discussed. AABM’s provide better results than traditional models in scenarios like road pricing and switchable trips and can answer questions on topics like health, home-activities, parking rates and emission zones.

6.5.3 Emerging policy questions

Workshop participants engage in a discussion about emerging policy questions. One participant first asks a question about the potential of a new model to improve road safety, but the answer is negative. The model will not make a significant contribution, as the only thing a better model would provide is a better estimate of future intensities and thus exposition in terms of road safety risk. The conversation then shifts to the flexibility and adaptability of models to address new policy questions.

Participants reflect on the time it takes to build models and discuss the importance of a model that can be easily adapted to answer new policy questions without having to start from scratch. They stress the need to convince stakeholders that the new model can match the capabilities of traditional models while providing additional flexibility.

A specific question arises about the ability of AABMs to fully accommodate multimodal transport changes. The discussion suggests that activity-based models are better able to calculate complex trip chains involving different modes, including walking, cycling and public transport. The participants explore technical details, looking at the challenges and opportunities of modelling fully multimodal transport systems.

Later, the discussion turns to the practicality of modelling parking duration and the complexity of predicting when people pick up their cars in activity-based models. Participants acknowledge the difficulties but stress the importance of effective communication and presentation when communicating model results to stakeholders.

The discussion ends with reflections on the impact of activity-based modelling on communication and stakeholder engagement. Participants share experiences on improved communication and successful presentations through the application of ABMs. Workshop participants recognise that while ABMs have advantages, it may not be a one-size-fits-all solution and a portfolio of models may be needed to effectively address diverse questions. The conversation highlights the ongoing challenges and need for continuous adaptation in the field of traffic and transport modelling.

Concluding, the participants gave different views on emerging questions. The provided the following examples: the contributions to road safety, the support in effective stakeholder engagement, representation of multi-modal transportation (incl. walking and cycling), vehicle retrieval time, and parking durations.