TAG Unit M5.4

Agent-based Methods and Activity-based Demand Modelling

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Department for Transport

Transport Analysis Guidance (TAG)

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This TAG Unit is guidance for the **Modelling Practitioner**

This TAG Unit is part of the family **M5 - Advanced Modelling Techniques**

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1. Introduction

1.1 This TAG Unit

1.1.1 In transport modelling, agent-based methods simulate travel-related decisions at the level of the individual and aim to replicate the behaviour of individuals (or agents) as they interact with other agents, and the environment in the wider transportation system. Activity-based demand modelling is an example of an application of agent-based methods, where individuals and their activities are modelled.

1.1.2 Activity-based demand models have some similarities to “standard-type” models, where travel demand is derived from peoples’ needs and desires to participate in activities, but for activity-based demand models, these concepts are extended to cover the activities to be carried out by each individual and how they are linked. Activity-based demand models focus on individuals’ or agents’ activities, and not just trips or tours as in standard methods.

1.1.3 These approaches allow analyses to be carried out at the level of individuals, and how these individuals travel across the whole day. Therefore, agent-based methods and activity-based demand models provide the ability to represent how different individuals or agents respond differently to changes in transport conditions.

1.1.4 This unit introduces agent-based methods and activity-based demand modelling and aims to illustrate where these approaches could be considered and how they may be used to form part of an evidence base to answer policy questions.

1.1.5 This unit explains the background to and operational elements of agent-based methods and activity-based demand models, as well as examples of their applications. The unit sets out principles of validating these models, however, it does not provide detailed guidance on how to develop these models.

1.1.6 The use of these models in economic appraisals still requires further research, but they can be valuable tools when used to explore policy options, as well as at an early stage of business cases when considering the strategic dimensions.

1.2 Proportionality

1.2.1 The full scope for designing and developing agent-based and activity-based demand models is very complex and can be disproportionate for some applications. At the time of guidance publication, there was limited evidence on the use of this type of models in the economic appraisal of business cases.

1.2.2 The flexibility of agent-based methods and activity-based demand modelling allows for a wide range of implementations and allows models to be tailored to specific use cases. At the same time, this flexibility poses a challenge to their description and explicit definition, as well as the calibration and validation of such models.

1.2.3 Analysts for major transport schemes are encouraged to engage with the Department in the early stages of their project to agree the modelling capability that is appropriate and proportionate for the schemes being tested. Where models are developed for scheme appraisal purposes, it is recommended to follow the appraisal specification process at the beginning of the project, described in The Transport Appraisal Process. The production of an Appraisal Specification Report is a useful record of the agreements on the scope of the appraisal and model, including those reached with relevant stakeholders, in particular, between scheme promoters and sponsors.

1.3 Structure of this Unit

1.3.1 This TAG unit describes the use of agent-based methods and activity-based demand models in the context of transport modelling:

- Discussing the relevancy of these methods and the additional insights they can bring (section 2)
- Defining what agent-based methods are and how they can be applied in transport modelling (section 3)
- Discussing modelling components of activity-based demand models and examples of model applications (section 4)
- Defining the technical considerations of developing agent-based and activity-based demand models, including data requirements and model calibration and validation (section 5).

2. Rationale

2.1 Emerging Questions

2.1.1 Transport modelling requirements are evolving, as there is a desire to understand the broader impacts of transport interventions or policies that require increasingly complex analyses in a more granular level.

2.1.2 Some of these questions may be handled using standard models with a more refined segmentation. However, some modelling challenges will require new analytical approaches, where individual modelling with dynamic interactions between supply and demand is needed (for example, when modelling demand responsive transit).

2.1.3 Outputs from transport models may be required to help inform:

- **Finer resolution** – a more disaggregate treatment of journeys, distinguishing active or 'final mile' mode stages, and representation of active modes could extend the modelling capability to provide metrics associated with health and climate change. Resolution is important in the context of understanding temporal and non-peak distributions.

- **Growing travel choice** – understanding how the growing complexity of individual travel choice results in complex competition between all modes in the transport network. We have seen new and innovative modes which are increasingly encouraging inter-modal travel and expanding mode choice. Individuals may now face more travel options with varying and dynamic benefits and disbenefits, with constantly evolving costs that may change as demand changes.

- **Representation of new and disruptive modes of transport with dynamic interactions between supply and demand** – representation of new mobility modes with their finer resolution and enabling a responsive nature to demand. This can also capture the ability of individuals to respond dynamically to network conditions via real-time updates in journey time applications.

- **The effects of interactions and constraints on behaviour** – the relationship between users, their behaviours, and their individual environment. For example, passengers and drivers with shared vehicle use from the same household.

- **Distributional impacts** – consideration of the range of distributional impacts, especially social and environmental. There are existing approaches to assess these impacts. However, a key challenge is to understand how different policies or interventions influence different users, especially vulnerable groups.

2.2 The Standard Model

2.2.1 The standard modelling structure is defined in TAG Unit M1.1 Principles of Modelling and Forecasting. Transport models using this standard structure are often called standard models, classic models or four-stage models. For consistency with other TAG units, the term “standard model” will be used throughout this document.

2.2.2 The standard modelling approach has been developed for modelling transport demand and supply, based on economic principles. The approach uses aggregate implementation methods with trips/tours from/to zone centroids as the main unit of analysis, and destination, mode, time of travel, and route choice, as the main choices considered.

2.2.3 Standard transport models are widely used in the UK to appraise the merits of investment in highway infrastructure, public transport infrastructure and services, and appraising other transport interventions. Practitioners should refer to TAG Unit M1.1 Principles of Modelling and Forecasting and Guidance for the Technical Project Manager for general guidance on the rationale for modelling and the considerations for specifying the model, linked to specific model objectives.

2.2.4 Standard demand models can be specified to reduce the level of aggregation by partitioning demand segments into disaggregate groups. This includes introducing detailed demand segmentation by factors such as trip type, income, age, household type, and car availability. As policy questions become more complex, standard models have trended towards deeper levels of disaggregation with improvements in data and computer capability. However, there is a trade off with finer disaggregation and the need to add interactions between these distinct groups.

2.2.5 Standard models consider the characteristics of aggregated individual trips or tours. Trip-based models seek to represent an individual’s travel choices for each individual trip, but they do not consider how trip choices throughout the day are interrelated. Standard tour-based models recognise the connection between the trips that are included in a tour, such as which modes are feasible for use in return trips, or a representation of park-and-ride.

2.2.6 Standard models generally ignore in-home activities (and their impact on out-of-home activities), and interactions between household members, such as access to household cars, other than through aggregate and fixed assumptions (for example, a certain proportion of trips to work can be replaced with remote working).

2.3 Agent-based Methods and Activity-based Models

2.3.1 The terms agent-based and activity-based are often used interchangeably, yet they cover different concepts. Agent-based modelling is used in a wide variety of fields, one of which is transport modelling. Activity-based demand modelling is used solely in travel behaviour modelling. They are distinct modelling techniques which are sometimes used together. This section defines both agent-based methods and activity-based demand models independently and discusses their application in combination with each other.

2.3.2 Agent-based methods simulate travel-related decisions at the level of the individual. This method aims to replicate the behaviour of individuals (agents) as they interact with other agents, and the environment, and how this manifests in the wider transportation system. Agent-based methods are widely used in other domains to understand complex system interactions, for example in economics, physics, and biology. Due to their more detailed nature, they may require more complex surveys or data.

2.3.3 Agent-based methods offer the potential to understand how aggregate system behaviour may change as user travel behaviour evolves in response to influences, such as changing working patterns, travel charging, or new technologies. Their bottom-up[1] nature allows for scenario testing of large-scale policies as well as targeted local policies.

2.3.4 Agent-based methods are already widely used in transport modelling. Common examples of agent-based methods in transport modelling are:

- pedestrian modelling
- microsimulation traffic modelling
- dynamic assignment modelling
- activity-based demand modelling

2.3.5 Activity-based demand models are an example of an application of agent-based methods. Activity-based demand models are not required to be agent-based, however, there is a trend towards their joint use in strategic transport modelling (Miller, 2019).

2.3.6 Activity-based demand modelling approaches consider that travel demand derives from peoples' needs and desires to participate in activities. They use behavioural theories about how individuals make decisions about activity participation in the presence of constraints. This includes decisions about when and where to participate in activities, and how to get to these activities.

[1] Agent-based methods are often referred to as being bottom up due to the emergent nature of their formulation. When building the model, the focus is on abstracting the system to its constituent parts (agents), then modelling the system as an output of interactions between these parts (agents). The model therefore flows from the bottom, the agents, up to the system itself.

2.3.7 The implementation of agent-based methods in activity-based demand models requires detailed modelling of individuals or agents and their activities. These models can be specified to model both individual activity behaviour and interpersonal linkages between individuals. This is required to capture household decision making for participation in some joint activities (such as school escort trips) and access to car, which results in consistency at the individual and household-level.

2.3.8 Activity-based models focus on individuals' or agents' activities, and not trips or tours. However, trips/tours can be derived from the connection between activities, and agents may make only one trip in a day (e.g. from home to airport), simple or complex tours or multiple tours. An activity-based model will generate activity and travel plans (discussed in section 4). Figure 1 presents a very simple activity and travel plan. Home, work and home are presented as activities, with travel, in the form of simple trips, between home and work, and then work and home.

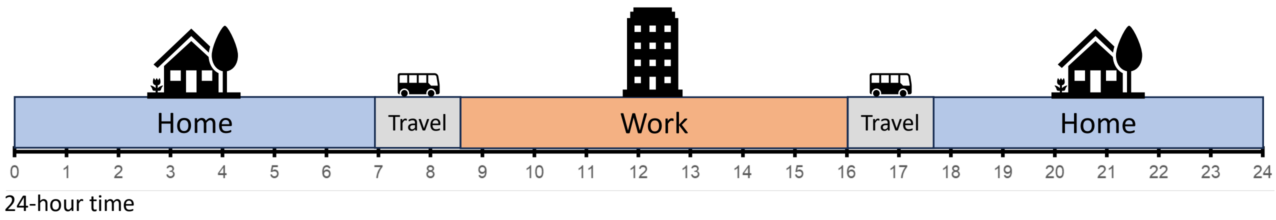

Figure 1 Illustrative Activity and Travel Plan

2.3.9 The key potential benefits of activity-based demand models are their more realistic and detailed representation of the motivation for travel, interrelated decision making, and the level of detailed information provided in their outputs. However, there may be additional costs associated to this enhanced level of detail, including the requirements for particular data and new demand surveys.

2.3.10 Activity-based demand models have many similarities to standard models (as described in TAG Unit M1.1 Principles of Modelling and Forecasting), where activities and trips are generated, destinations for activities are modelled, travel modes are identified, and ultimately trips are assigned to a transport network. In addition to this, they share many similar concepts such as, the use of choice modelling, and other statistical and econometric modelling, but that these concepts are extended to cover the activities to be carried out, and how they are linked.

2.3.11 Activity-based demand models can represent time and space constraints realistically, show linkages among activities and travel for each individual, as well as across multiple individuals in a household. This should enable these models to better represent the effect of travel conditions on people's activities and hence travel choices and vice versa.

2.3.12 The freedom when implementing agent-based methods and activity-based models can be more diverse than the standard model, as the nature of where and how agent interactions may occur is broad. For example, an agent-based method may be employed for household choices within an activity-based demand model using deterministic assignment. Agents may interact in a household vehicle model, competing for access to it. Conversely, an agent-based approach may be used in a narrower context, for example, solely in the traffic assignment model, modelling traffic in a micro-simulation with a fixed origin-destination matrix input.

2.3.13 The advantage of agent-based methods and activity-based demand models is that they can provide more detailed evidence for emerging planning and policy questions, for example, where an agent can interact with other agents within the same household, or with other agents on the network or space (at the assignment stage). With these models, the data on individuals' activities and their travel plans are simulated and kept within the modelling process, so that the outputs of the models can be analysed.

2.3.14 Agent-based and activity-based demand models also allow interactions between activities and trips by the same agent, for example, a change in the location choice of an activity (e.g. work) affects the location decisions of the other activities in the agent's day travel plan. There are also transport schemes that may affect the whole day travel plan of an agent (i.e. all trips of the day) such that an agent decision (e.g., paying a parking charge to enter a town) is not only influenced by their trips in the plan but by the cumulative impacts of the schemes on all trips in their travel plan.

2.4 Illustration of Modelling Structure

2.4.1 The structure of agent-based and activity-based models can be similar to those of the standard models. Figure 2 and Figure 3 illustrate some possible variations of modelling structure and methodology.

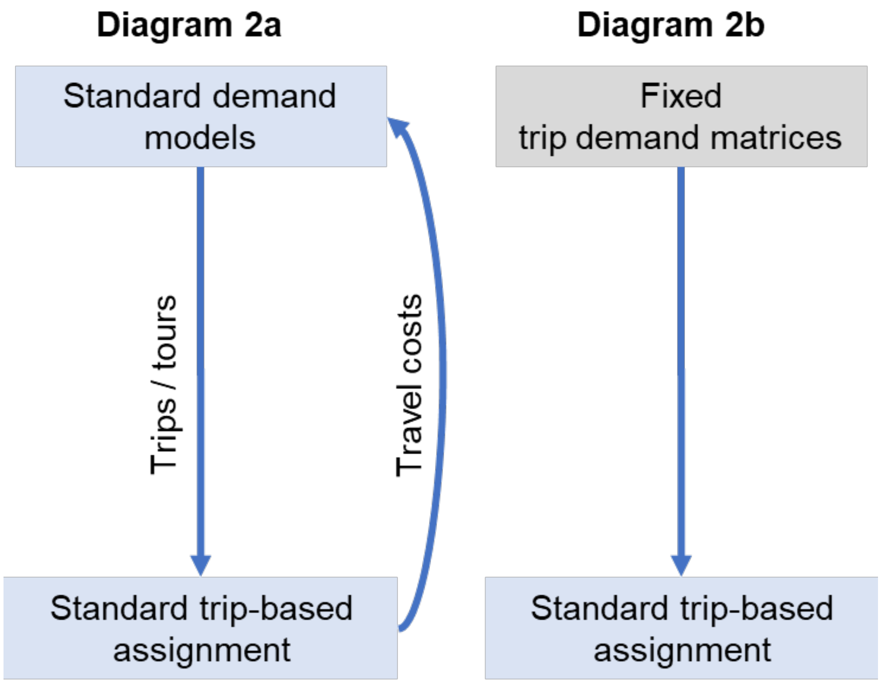

Figure 2 Standard Model Structure

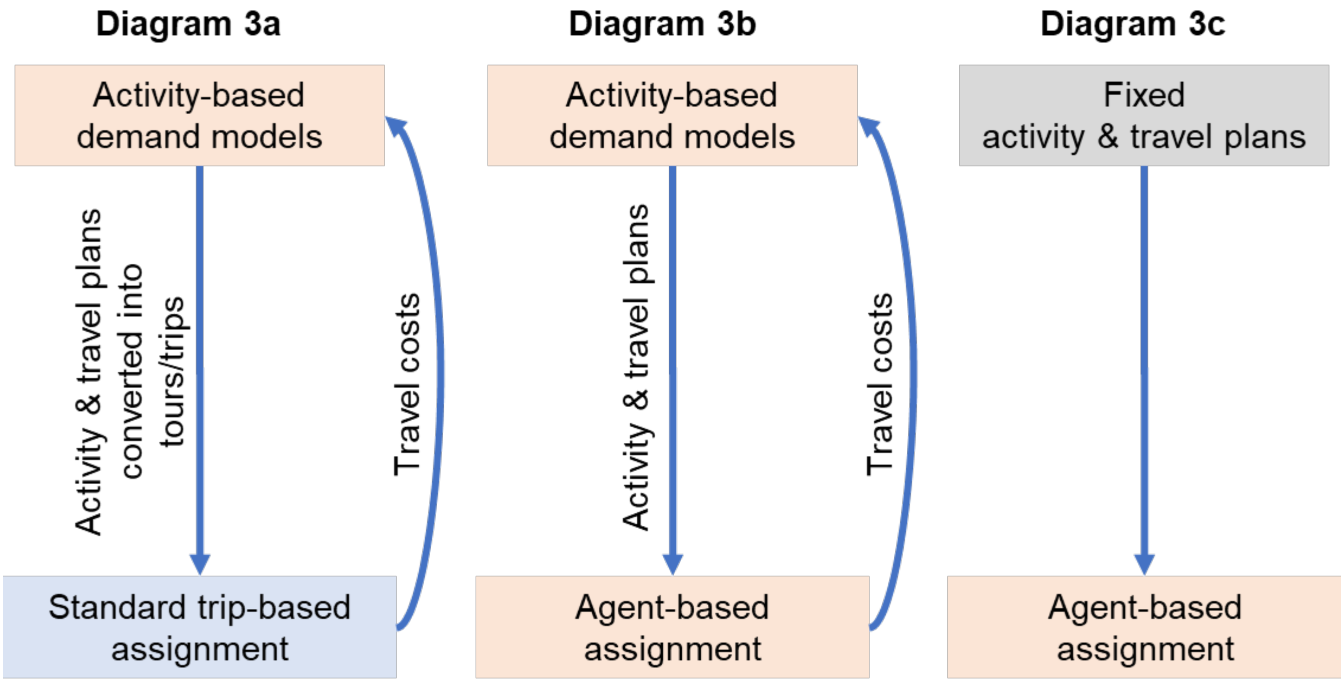

Figure 3 Model Structures with Agent-based Methods and Activity-based Demand Models

2.4.2 Diagram 2a shows a very simplified version of the standard model structure as described in TAG Unit M1.1 Principles of Modelling and Forecasting. There could be some variations or enhancement within the standard demand modelling methods, whether the models produce trips or tours, and whether they use simple demand segmentation (e.g. car ownership only), enhanced segmentation (e.g. car ownership, income, disaggregate demographic), or synthetic population of individuals. Regardless of the level of disaggregation of the demand, this type of model uses aggregated spatial areas where trip demand matrices are assigned to the transport network via centroid connectors of a zoning system. There is a demand-supply loop where the travel costs from the assignment model are fed back to the demand model, which capture the effects of demand changes as a result of changes in transport condition.

2.4.3 Diagram 2b shows the structure with fixed trip demand matrices when changes in travel costs will not generate a noticeable change in demand. Transport models that use fixed demand are inadequate for most transport schemes where changes in demand are expected, as described in TAG unit M2.1 Variable Demand Modelling.

2.4.4 Diagram 3a shows a structure with activity-based demand models that produce activity and travel plans for an individual or an agent (this is explained further in section 4). In this structure, the standard trip-based is used as an assignment method, which is the same as the assignment methods in Diagram 2a and 2b. This structure uses similar demand-supply loop as in Diagram 2a, where changes in transport conditions will change demand at the level of individuals with their activities and travel plans.

2.4.5 In Diagram 3a, the travel plans produced by the activity-demand model are extracted into tours or trips so they can be assigned to the network. For example, to create a one-hour (e.g., 8am-9am) trip matrix, all trip records with departure or arrival times between 8am-9am are extracted from the travel plans. The aggregated costs from the standard trip-based assignment model are assumed for all with departure/arrival times within the same hour (e.g., 8am-9am) in the activity-based demand model. The breakdown of cost changes within the hour will not be captured and it is assumed that all experience the same network conditions and hence use the same costs values (e.g., time, distance, toll). However, these cost changes will still be applied to all, so that activity and travel plan for each individual or agent can be estimated within the activity-based demand model.

2.4.6 Diagram 3b has the same activity-based demand models as in Diagram 3a, however, the assignment stage uses agent-based methods (discussed further in section 3) where each agent with their activity and travel plans are assigned to the network. Unlike trip-based assignment in Diagram 3a, in this case, the agents may compete with each other across time and space in an interaction-based traffic model (such as a microsimulation model). These agents may be modelled going to specific and detailed locations (not aggregated spatial areas, e.g. zones) for their specific activities (e.g. school location for an education trip). The demand-supply loop is also used in this structure with travel costs being fed back to the activity-based demand models. This structure uses very detailed demand and assignment models, which may increase the efforts and resources required to calibrate and validate the models, as well as ensuring that the model convergence is satisfactory, or the model results are stable.

2.4.7 Diagram 3c uses fixed demand, which is similar to Diagram 2b, however, rather than fixed trip demand matrices, this structure has fixed activity and travel plans as input to the agent-based assignment models. There is no feedback loop between demand and supply so the models will not be able to assess the impact of transport schemes on changes in individuals' activities. If a dynamic agent-based assignment is used, changes in time-of-day, destination, and mode of travel at trips-level, may be simulated.

2.5 Considerations to Adopt New Approaches

2.5.1 A key concept of guidance is that modelling should be proportionate and appropriate for the use cases in question. The travel choices that are represented, the interactions and constraints that are applied, the solution methods used, can all be different, but they should be appropriate for the task to which they are applied, and their implications for the interpretation and use of the model results should be carefully considered and presented.

2.5.2 Practitioners who consider adopting agent-based and activity-based approaches should give thought to the following:

- The scope and objectives of the model. These models can be useful tools for long-term planning, exploring strategic policy options, or developing strategic dimensions at an early stage of business cases for transport schemes. The broader range of behaviours and influences represented in agent-based and activity-based models are not fully represented in the current economic appraisal methods set out in TAG unit A1.3 User and Provider Impacts. The use of these approaches in economic appraisals can be considered, however, it requires additional consideration, including overcoming challenges in the robustness of calibration and validation of agent-based and activity-based models. Practitioners must provide evidence of the validity of their models for the purpose they use them for.

- The type of interventions that will be explored using the models, whether they are new infrastructure, new policies, dealing with new technologies and uncertainty, for example, infrastructure and investment for new modes, mobility as a service, or demand responsive transport.

- The behavioural responses that must be modelled to estimate the impact of these interventions in terms of benefit analysis, equity, and environmental impacts, for example:
  - Route choice only
  - Route and mode choice
  - Route, mode and destination choice
  - Trip generation, time of day, destination, mode and route choice
  - Activity generation, activity scheduling, location choice and mode choice
  - Re-scheduling of individual activities in a day
  - Re-allocation and scheduling of household activities in a day or in a week
- Data requirements and the balance between the limitations of the data and the granularity of the model affecting the reliability of any forecast.

2.5.3 Standard models have been used to assess the impacts of transport schemes and provide evidence to the economic appraisal of business cases. There may be alternative investments and policies that are difficult to test using the standard models, where analyses at the level of individuals, and how these individuals travel across the entire day, are required. For example, a demand management policy (such as journey to work incentives to discourage car use) may be assessed using an activity-based demand approach that allows an assessment of individuals, where they live, where and how they go to work, their level of car use and accessibility to other modes, as well as their activities throughout the day and whether they might modify their activity participations and change mode of travel. Agent-based and activity-based demand models provide the ability to represent how different individuals or agents respond differently to transport schemes.

2.5.4 Other policies or schemes that may benefit from an agent-based and activity-based approach are those sensitive to variation by time of day, and their effects on whether individuals will substitute more out-of-home activities with in-home activities, and how the benefits accrue to different populations. Practitioners are encouraged to engage with their project sponsor in the early stages of their project to agree the modelling capability that is appropriate and proportionate for the schemes being tested.

3. Agent-based Methods

3.1 Introduction

3.1.1 This section focuses on agent-based methods in general, and then in the context of strategic transport modelling. It also introduces the key modelling terms and concepts that are used in agent-based methods. Advice relating to microsimulation methods is available in TAG Unit M3.1 Highway Assignment Modelling.

3.2 Modelling Terms

3.2.1 An agent-based method generally consists of an **environment**, **agents**, and **agent interactions** and **strategies**. This is graphically shown in Figure 4.

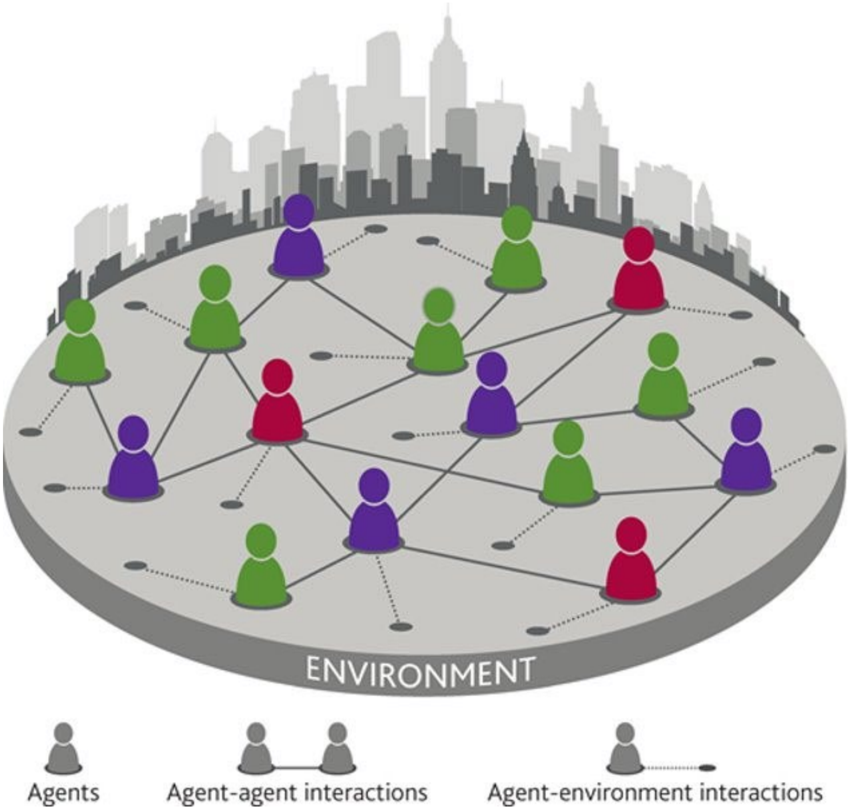

Figure 4 Agent-based Methods: Understanding the Economy from the Bottom Up (Turrel, 2016)

Environment

3.2.2 The **environment** may represent the transport supply, for example the network, land use, or public transport schedules.

Agents

3.2.3 Agents can be anything that are expressed as separate decision-making units for which rules can be assigned. The **agents** may represent individual travellers, or a bus, train, or vehicle. This will often be done via the creation of a synthetic population of agents, with their respective attributes and trips, tours, or activity-travel plans.

3.2.4 Crooks et al. (2018) defines agents as being **autonomous**, **heterogenous**, and **active**.

- Agents are **autonomous**; they are independent and not centrally controlled. Agents make their own decisions, with limited or total knowledge of the environment around them. There may be some exceptions to this, for example, Demand Responsive Transit agents may be centrally controlled by a dispatcher which instructs them on how to behave.

- Agents are **heterogenous**; they are generally programmed to be different from each other, either directly or indirectly. They may be assigned different characteristics, such as age, income level, or behavioural response. In many cases an agent-based method will make use of a synthetic population (described in Section 4.4) which consist of heterogenous agents.

- Agents are **active**; Table 1 (derived from Crooks et al., 2018) describes, with examples, the ways that agents may be active.

Table 1 Examples of Agent Behaviours

Active	Description	Example
Goal directed	Agents aim to achieve something	An agent aims to complete a series of activities
Reactive	Agents are aware of the environment around them	An agent reacts to congestion on a road by trying other options
Rational	Agents choose rationally (this may be bounded)	An agent maximises their utility
Interactive	Agents interact with their environment or other agents	An agent reacts to other agents (directly or indirectly via shared environment)
Mobile	Agents explore their modelled environment (the spatial component)	Agents explore various parts of a transport network

Interactions and Strategies

3.2.5 The agent interactions and strategies describe how agents make decisions, what information they use, and, critically, how decisions are influenced by other agents or the environment. This may be simple (for example, random) or complex (for example, using externally calibrated discrete choice models). Agents may interact directly with each other (for example, in a household for car access) or indirectly via their environment (for example, by generating traffic on a road).

3.3 Key Features

3.3.1 A dynamic agent-based simulation can allow for the system processes to be analysed at the level of their constituent element. This allows a better understanding of the agents involved, their stochastic and heterogeneous attributes, and how their complex interactions lead to exhibited macro level behaviour. Agents use decision making rules (for example choosing the shortest distance path) or heuristics (for example taking the earliest available bus departure) for behaviour influencing the interactions with each other and their environment.

3.3.2 The nature of these interactions can be implemented in various ways, reflecting the flexibility of the agent-based approach and its ability to be tailored to a given use case. This flexibility allows agent-based methods to be used for a wide range of applications, but also means it is therefore challenging to define them explicitly.

3.3.3 Agent-based methods in transport can consider more complex system behaviour as typically they cover longer time periods (for example, a day), simulate agent behaviour at a fine timescale (for example, 1 second), and can reflect how interactions at one part of the day influence behaviour at other times. Agents may maintain knowledge of their previous experience as they travel through the day, rather than experiencing morning, inter-peak, or evening peak, in isolation. Examples of this would include parking charges that could occur at different points of their day but then influence other decisions.

3.3.4 Agent-based methods are sometimes used to capture complex and emergent phenomena. Many modelling methods struggle to capture how a system may evolve and change, resulting in tipping points and cascading effects as the underlying dynamics may shift significantly (Batty, 2007). Agent-based methods with extremely simple agent decision making rules can exhibit complex aggregate behaviour. This contrasts with statistical methods that are (robustly) calibrated against historical behaviour but are generally unable to capture emergent behaviour (Bonabeau, 2002). Agent-based models in transport may have the potential to generate interesting and plausible new future arrangements.

3.3.5 The use of heterogenous agent populations has applications of relevance to multi-scale, multi-system, and distributional impacts. The use of a synthetic population of agents may provide a better understanding of the distributional impacts of interventions across income, social status, employment type, or age.

Growing Travel Choice

3.3.6 The travel options available to transport users have increased in recent years, with the emergence of novel business models and travel modes. For example, many cities now feature dynamic car rental schemes that can challenge standard car ownership assumptions, or new modes, such as e-scooters and autonomous vehicles.

3.3.7 In addition to increased mode choice, the options for other choices have also expanded. For example, location choice has increased, as a result of increasing speed in building use changes and even land use changes, and trade-offs between ordering goods online (generating freight demand) or travelling to collect goods (generating public transport, active, or car-based demand).

3.3.8 An agent-based method provides an opportunity to explore individuals' choice of travel with the potential to capture emergent behaviour. Since an agent-based method permits for phenomena to emerge from agent interactions, exploration of agents' behaviours and risks (in either inputs or model parameters, or both) might be explored in combination.

3.3.9 Similar to the standard method, agent-based methods, coupled with Monte Carlo methodologies, can also be used to help ascertain how sensitive (or not) a system may be to single or multiple sources of uncertainty. This modelling does pose challenges for model interpretation (ensuring signal and noise[2] are understood) and when passing modelling insights to down-stream decision-making systems, which may not be setup to handle more uncertain inputs.

Dynamic Interactions between Supply and Demand

3.3.10 The rise of smart phone, real-time network information, and increasing activity flexibility, has permitted transport users to respond and adapt to real-world conditions faster than before. As this flexibility increases, there is an interest in capturing this dynamic relationship between supply and demand in modelling. This is a challenge that agent-based methods are particularly suited to tackling.

[2] Signal refers to model outputs that are meaningful, and of significance to the phenomena being studied. Noise refers to model outputs that are not meaningful, but a relic of the modelling approach and of no significance to model interpretation.

3.3.11 Agent-based methods tend to be employed in a similar supply and demand manner as standard modelling practices. Modelling supply side components as agents, which may dynamically change their behaviour in response to other agents, allows additional transport options to be modelled, such as Demand Responsive Transit (DRT). The supply side of such services requires the identification of vehicles and dispatchers as agents attempting to serve individual users in the most cost-effective manner.

Representation of New and Disruptive Modes of Transport

3.3.12 The ability to abstract to the concept of an individual (an agent) is a useful modelling feature when considering the possible impact of new and disruptive modes of transport. By definition, there are typically no or limited historical data with which to calibrate a more traditional statistical model for these emergent modes.

3.3.13 Many new modes have a dynamic supply side behaviour which responds to travel demand. They are not static, scheduled services, but services which adapt and change in response to evolving user needs.

3.3.14 In an agent-based method, an individual may be used as the means to reflect and relate estimated physical or cost parameters of a new mode. The agent may use an existing decision-making function to assess how they may appraise these new options, compared to their existing choices.

3.3.15 The supply side may also be represented as a series of agents, with behaviour to respond to the changing travel demand (for example, routing new demand responsive bus services). An agent-based method may be employed for both the supply and demand side, permitting for close coupling of these interactions.

Model Challenges

3.3.16 The connections between spatial scales are a known modelling challenge. Generally, models have been tailored to focus on different spatial dimensions, and/or modes. This is often reflective of the decision-making application of the model (for example, they are for different users, with different concerns) but also due to more technical reasons, such as data availability, computing power, and methodological confidence.

3.3.17 In recent years, the increase in availability of diverse data sets has enabled more robust cross scale methodologies (permitting for the modelling of local transport choices all the way up to strategic or even national choices). The improved access to high end computing hardware (for example via the cloud) reduces the barrier to entry for computationally demanding work footprints.

3.3.18 The level of detail associated with an agent-based methodology may be useful in crossing scales, as the representation of agents allows a range of agent choices to be supported in a very diverse and detailed environment. For example, a multi-modal network that has resolution at the local level, and at a national scale. In recent years, such simulations are possible due to computing advancements, so such models can be practically implemented. The challenge is more related to validation of these methods at various scales, to ensure that meaningful insights can be gained.

3.4 Application of Agent-based Methods

3.4.1 In the context of strategic transport modelling, an agent-based methodology may be used for a range of decision making (choice) components. These may be undertaken in isolation, or in part of a wider model with multiple choice types.

3.4.2 A critical component of any agent-based method is the nature of the agent definitions and their respective interactions. Any model specification should focus on an assessment of what agent interactions are of significance to their policy question or use case and develop the model in this context.

3.4.3 In the context of strategic transport modelling, it is likely that the decision-making mechanism for an agent will involve the formulation of a utility function, with which the agent may appraise the merits of different options. This function may be anchored in the fundamentals of demand (for example, an activity-based model) or in a classic random utility theory of choice depending on the use case and level of complexity required.

3.4.4 The possible choices that an agent-based methodology may be employed may be similar to those of standard models, for example:

- route choice: where agents interact in a traffic assignment model, creating traffic and influencing decision making via journey times.
- mode choice: where agents make attribute specific decisions based on heterogenous preferences, influenced by route choice and household car availability.

3.4.5 The application of agent-based methods in activity-based demand models involves the creation of activity plans for each agent. Agents may then seek to achieve their desired activity plans by optimising their travel choices, usually in competition with each other. The competition or interactions between agents in time and space may be within households for car access, in public transport via crowding or in the generation of traffic through traffic assignment. There is flexibility in how these different aspects may be modelled. For example, traffic assignment may be agent-based assignment or standard assignment methods (as discussed in section 2.4.

4. Activity-based Demand Modelling

4.1 Introduction

4.1.1 This section introduces the key modelling terms, concepts, and key features that are used in activity-based demand models. This section also discusses model components and an application of activity-based demand models.

4.1.2 Activity-based demand models represent travel demand as derived from the individual's needs and desires to participate in activities. Activities can be performed virtually, as well as physically, while at home or at an out-of-home location, or even during travel. Activities that take place outside the home will generate travel.

4.1.3 Several operational activity-based demand models have been developed and used for transport planning and policy analysis over the last three decades, primarily in North America and in some places in Europe (SHRP 2, 2015; Vovsha et al., 2004; Vovsha et al., 2006; Arentze et al., 2000; Arentze et al., 2004; Rasouli et al., 2014). Recently in the UK, there is one operational activity-based model developed by Transport for London (Blair et al., 2023), and there may be other activity-based models currently being developed elsewhere in the country.

4.2 Modelling Terms

Activity

4.2.1 An **activity** defines a particular use of time by an individual, when engaging in any behaviour – all time is consumed by an activity, even if it is waiting, sleeping, or 'doing nothing'. This differs from typical 'trip purposes' as they tend to only capture a sub-set of daily out-of-home activities where travel is generated. In practice, it may not be possible to include all activities, therefore, a selection of the most salient activities (in particular those that are likely to influence travel) must be adopted.

Activity Duration

4.2.2 The **activity duration** is defined as the amount of time elapsed to undertake an activity.

Activity Episode

4.2.3 An **activity episode** is defined as a single occurrence of an activity.

Activity Diaries

4.2.4 Activity-based demand modelling may use specific **activity diaries** that gather data of individuals and their activities over the course of a day (or multiple days), including the associated travel. An activity diary can be designed in different ways, depending on the purpose of the study and differs from traditional travel surveys in that it focusses on the activities which then derive travel demand.

4.2.5 Existing activity diaries are available from the UK Time Use Surveys collected in 2000-2001 and 2014-2015 by the Office of National Statistics (ONS) and the National Centre for Social Research (NatCen). There is also time use data that has been collected in the ONS Time Use Survey (OTUS) on an experimental basis since March 2020.

4.2.6 Household travel diaries have also been used as pseudo non-home activities diary. There may be some gaps in the data when using travel diaries in activity-based models due to, for example, poor capture of at-home activities, limited set of purposes, and sometimes challenges of linkage between household members. Existing travel diaries, such as the National Travel Survey, are discussed in TAG Unit M1.2 Data Sources and Surveys.

4.2.7 Activity diaries gather information on:

- what activities were undertaken and travel done (derived from these activities) during the defined time period (types and frequency)
- modes used for travel
- in what order were activities/travel undertaken
- at what time and for how long were activities/travel undertaken
- where were activities undertaken (allowing for the recording of multiple activities at the same location)
- with whom were activities undertaken
- any other activity/travel associated information

Primary and Secondary Activity Episodes

4.2.8 Most activity diaries and time use surveys make a distinction between '**primary**' and '**secondary**' activity episodes. This provides a way to include situations when people multitask.

4.2.9 The activity episode with the highest priority is considered to be the primary one and subsequent, lower priority activities may be arranged around this activity. This classification plays an important role when evaluating time spent on activities.

4.2.10 For example, the primary activity episode when socialising on the phone while shopping at the supermarket would be expected to be shopping at the supermarket. Assigning priority to each activity episode depends on the combinations of activities that an individual undertakes, and this might be treated differently under different circumstances. For example, either the shopping or the socialising could be considered as the primary activity episode, depending on the circumstances.

Activity Pattern

4.2.11 The **activity pattern** is defined as a set of activities undertaken by an individual over one day, including activity types, locations, and travel required to perform those activities.

Activity Schedule

4.2.12 The **activity schedule** is defined as the process of timetabling a sequence of activities conducted for one day (or longer period of time). The activity schedule supplements the activity patterns with the start time, end time and duration to the activities. If the sequence of activities is treated as fixed and only their duration and timing is variable, then the model is in essence a tour-based one. The re-planning of activities, including the negotiations among member of the household to allocate them, is one of the important parts of activity-based demand models.

Activity Stops

4.2.13 **Activity** stops are defined as the points, usually associated with a particular land use, where a movement ends. One or several activities can be conducted at each location.

Tours and Trips

4.2.14 A **trip** is defined as a movement between two stops where activities are carried out. A **tour** is defined as a closed sequence of trips, starting and ending at the same stop. Tours usually either start and end with a return to home, or to/from a school or workplace. These definitions are the same as those used in the standard models.

4.3 Key Features

Modelling Activities

4.3.1 Activity based models are based on the principle that travel is derived demand from individual’s wishing to carry out activities. Activities are the actual goal of individuals, and this may evolve and change over time, resulting in changes in associated travel demand.

4.3.2 The use of activities allows the model to explicitly produce activity plans, which include whether or not to carry out the activity, where to carry out the activity (at home or out-of-home), when to carry out the activity (scheduling), how long the activity lasts (duration), any travel modes associated with the activity, and the subsequent impacts on tours and trips. By modelling activities, these models can respond to policies such as changes in the duration of activities or flexibility in working hours which may not explicitly affect trip generation but do impact the time constraints of trip making. Although these policies may be approximated in the standard model an activity-based approach offers greater potential to model at the resolution of the behaviour driver, the activity itself. Modelling activities also allows for the substitution of out-of-home activities with in-home activities, including shopping online and working from home. Modelling activities may also provide additional clarity on responses to policies which vary by time-of-day, such as fare policy, as a function of other time constraints, and not only the cost of the trip.

Interrelated Decision Making

4.3.3 Activity-based demand models represent the interrelated aspects of activity and travel choices for individuals, including purpose, location, timing, and travel modes. This leads to a more consistent representation of tours and trips.

4.3.4 These models can incorporate intra-household interaction in which household members coordinate activity participation (such as, the use of car in household, pick-up/off of children at school). The intra-household interaction provides internal consistency at both the person and household level, which may provide a more realistic estimation of share-ride trips. However, this may require new form of surveys and data collection.

Detailed Information

4.3.5 Activity-based demand models could include explicit and detailed modelling of in-home / out-of-home trade-offs, time-of-day choices, times spent engaging in activities, the arrival and departure times, and activity duration.

4.3.6 The level of detailed outputs from these models allows further understanding of the impact of specific policies or transport schemes on different socio-economic groups, at a fine spatial and temporal resolution. When activity-based demand is assigned to a network using an agent-based assignment model, this feature also allows additional granularity in how changes, such as vehicle kilometres travelled or emissions, can be attributed to individuals, household types and socio-economic groups. This is due to the link between the individuals (agents in a synthetic population) and the demand segments / agent types that are represented in the activity-based demand model.

4.3.7 The temporally detailed information is especially critical for understanding the likely impacts of travel demand and transport system management interventions. For example, any intervention that suppresses trip-making by car during a certain part of day could result in temporal redistribution of activity-travel, replacing an out-of-home activity with an in-home activity, or eliminating a certain activity from activity-travel plan by an individual.

4.3.8 A greater level of granularity across model dimensions, however, may require forecasting inputs at that greater level of detail. When specifying a model, practitioners must assess the availability and quality of such data before proceeding into design. Where these data are not sufficiently available, the quality of the forecasts may lack sufficient assurance of validity to warrant the inclusion of that granularity.

4.4 Activity-based Demand Model Components

4.4.1 The structure of an activity-based demand model can be flexible, where it may follow data availability and the policy that the model will test. There are many ways to structure the sequencing and information flow between model components in activity-based models.

4.4.2 Hierarchy and structure of model components are required to be appropriately defined at the start of model development. Figure 5 (adapted from SHRP 2, 2015) shows an example of an activity-based model structure and its major components. This is not the only structure and design of activity-based demand models. Its purpose is to illustrate how model components might be linked to develop a model.

Synthetic Population

4.4.3 A synthetic population is a set of simulated households and individuals data that fits the distribution of people and their relevant attributes according to the observed demographics in the area being modelled. In an activity-based model, it is a key input to model population behaviour, as households and individuals are the core decision-making units that make choices, such as the number of vehicles owned, the type and number of activities, and the locations of work and school. Activity-based demand model systems normally require a complete synthetic population for the model region so that the activity and travel patterns of individuals can be simulated through the day.

4.4.4 Synthetic population models create detailed household and individual information that aims to be representative of the real-world population. The quality of this synthetic population depends on the sample size and how well it is allocated among relevant population segments.

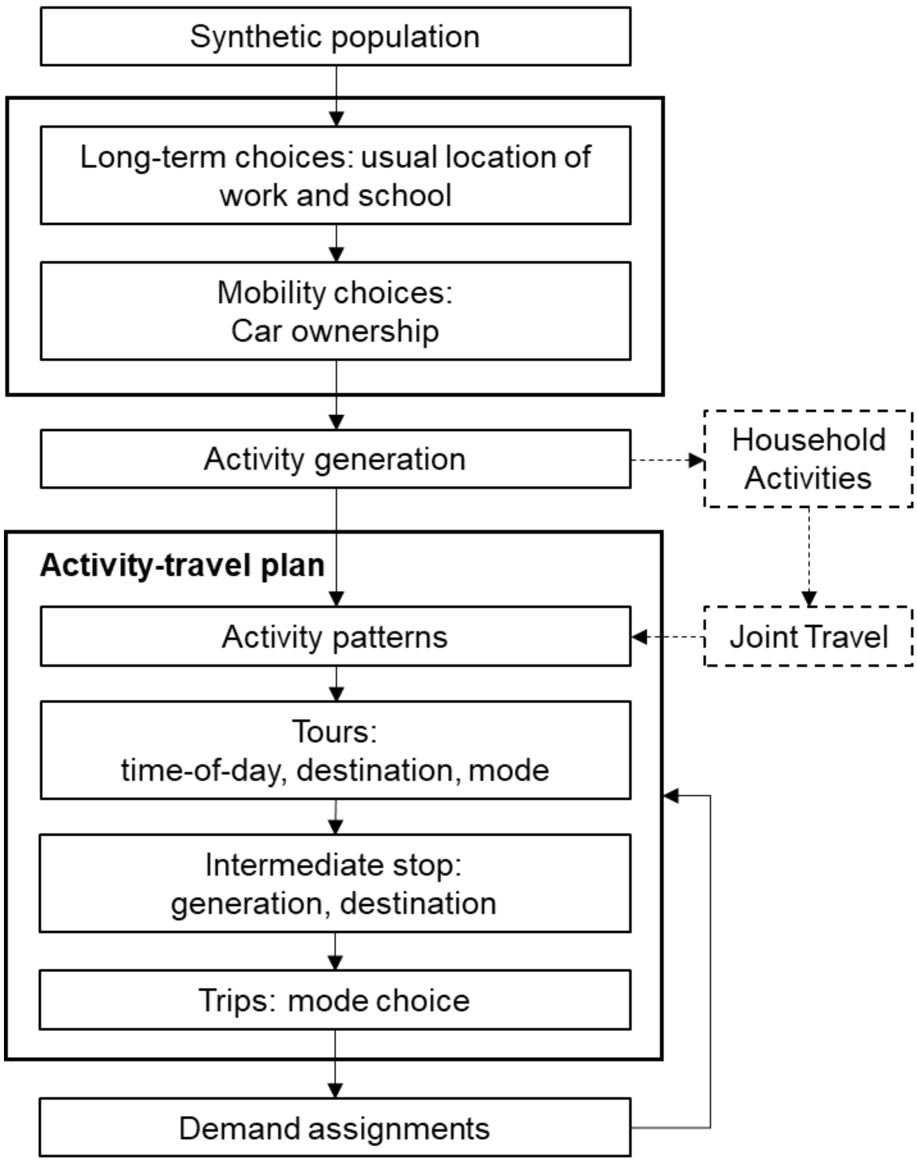

Figure 5 An Example of Activity-based Demand Model Structure

4.4.5 Generally, there are two methods for creating synthetic populations. One is synthesising using microdata and aggregate data and another is synthesising with only aggregate data. The use of microdata, for example from a household travel survey, provides real world synthetic individuals which can be used to "seed" realistic individuals. Sometimes seed microdata may not exist and statistical methods may be used to entirely synthesise individuals using aggregate data alone. Naturally this method presents challenges to ensuring individuals are then realistic.

4.4.6 When using microdata there are two primary data inputs to synthetic population models: control data and sample data.

- Control data are used to define a multi-dimensional distribution of households and population. The control data represent attributes that are explicitly accounted for in the generation of the synthetic population, however, they may be limited by what can be observed or obtained from data sources. These attributes may include household size, household income, household number of workers, and presence of children in the household. The control totals for the base year should be derived from Census data, or other representative population estimates, such as the Office for National Statistics (ONS) population data. The spatial detail of the available control data can vary from relatively disaggregate (such as Lower Layer Super Output Area total population controls) to more aggregate (such as Middle Layer Super Output Area gender split controls). Control data should be produced for the base and future year scenarios. The availability of demographic forecasts for an area should be considered when selecting which control variables to use in population synthesis.

- The sample or "seed" data used to generate the synthetic population should include detailed information corresponding to the control data. Local or regional household surveys, or the National Travel Survey (NTS), can be used as the basis for the disaggregate sample data.

4.4.7 The synthetic population should include all attributes specified for the activity-based model components. For example, if age group is used in the model, the synthetic population must include relevant information on age group. Where new models are estimated, variables (such as age distribution) in the survey data can be compared to those available in the synthetic population, as a mean to validate the models.

4.4.8 It is important that the design of a synthetic population considers the policy and planning analysis needs. For example, where analysis of specific socio-economic groups (for example, based on ethnicity, age, or income group) is needed, analysts should ensure that these attributes are reflected in the synthetic population.

Long-term Location Choices

4.4.9 The decisions of where to live and usual work or school locations influence day-to-day travel behaviour, but these decisions are made on a longer-term basis. In activity-based models, residential choice is often implicit in the population synthesis process. The usual work and school locations are essential anchor points for other activity and travel choices, and an option for the usual work/study location is work/study from home on a regular basis. Usual work and school locations can be modelled in a similar way to the destination choice in the standard models where the model predicts the choice of a single location from a set of alternative destinations (see TAG Unit M2.1 Variable Demand Modelling).

4.4.10 Alternatively, modelling such longer-term choices can be done outside of the activity-based model system, in which case a land-use / transport interaction (LUTI) model can provide estimates of the longer-term distributional effects of these choices. For advice on LUTI models, see TAG Supplementary Guidance – SI Land Use / Transport Interaction Models. The outputs from such models can be passed on to the activity-based demand model as a variable of the synthetic population.

Mobility Choices

4.4.11 Mobility choices are also decisions that influence day-to-day travel behaviour and are not made daily. Examples of these choices are vehicle ownership, vehicle allocation, and subscription to services such as Mobility as a Service (MaaS). The mobility options affect other choices, such as destination and mode choice, that create daily activity and travel plans of households and individuals.

4.4.12 Similar to the case of longer-term choices, mobility choices can be carried out outside of the activity-based model system. The outputs from these models, such as the number of vehicles owned in a household, can be passed on to the activity-based model as a variable on the synthetic population.

Activity Generation

4.4.13 The activity generation component defines a set of activities to be undertaken in a given period (24 hours, for example) by an individual or a household, taking into account the constraints on activity choices, such as capability[3] and coupling[4] constraints, and constraints on facilities opening hours.

4.4.14 The activity generation process estimates the attributes of frequency and destination type (whether the activity needs to be carried out in-home or out-of-home, or not at all) for a given day.

[3] Capability constraints are imposed by the limits of nature or technology. These constraints are mainly related to limitations on the activity of individuals because of their biological structure and/or the tools they can use. For example, humans need a minimum number of hours of sleep and they cannot be in more than one place at a time.

[4] Coupling constraints mandate the presence of another person or some other resource in order to participate in the activity. These are the limitations that define where, when, and for how long, the individual has to join other individuals in order to participate in the activity. For example, escorting a child to school or dropping off a partner at a train station.

Activity and Travel Plan

4.4.15 There may be many designs to model activity and travel plans in activity-based demand model systems. However, the key feature is that the model estimates the activity patterns, sequence of activities, activity scheduling, tours, stops and trips during an average day (in some cases it may be more realistic to adopt a weekly pattern, for example, for shopping or recreational activities). The model components of scheduling, or time-of-day, represent the dimension of time in activity and travel choices.

- **Daily Activity Pattern**: an activity pattern for each household member is generated, which includes activity type, frequency, and schedule of activities. The focus here is to estimate the number of tours that each individual makes for each of activity and tour purposes. The tour purposes are usually classified into some broad categories, indicating their general importance and priority in forming the day's activity and travel pattern. The tour purposes can include mandatory purposes (such as work and study), maintenance purposes (such as escort, medical, shopping, and personal business) and discretionary purposes (such as social and recreation).

- **Tours**: the main decisions modelled at tour-level are destination choice, mode choice and time-of-day choice. The concept is very similar to the standard models, however, in activity-based models tours are generated as part of overall daily activity patterns for each individual.

- **Stops**: intermediate stops can be simulated on the tours that occur during the day, which include frequency, their location (destination) and duration.

- **Trips**: the concept is similar to the standard model, where a tour consist of a series of trips beginning and ending at home or work or other anchor location. However, trips are not treated as independent, as the trip-level mode choice and time-of-day choice are conditional upon the tour-level choices, which are part of activity patterns.

4.4.16 Tours and trips made by an individual in activity-based models are interrelated across the entire day. The models also use information about tours and trips to apply constraints on the travel modes that are available, for example, an individual who travels to work by public transport will not drive home alone.

4.4.17 There is no standard practice for hierarchy to be used for modelling the mode, time-of-day, and destination choice dimensions. In reality, there is some degree of simultaneity across all three of these choice dimensions. An appropriate structure should be better estimated based on model applications and data availability by practitioners (for example, see TAG Unit M2.1 Variable Demand Modelling).

Tour and Trip Assignment

4.4.18 The main outputs from activity-based models are estimates of travel demand in the form of lists of detailed tours and trips, as opposed to aggregate trip matrices as in the standard models. This list of tours and trips looks like a travel diary from a detailed household travel survey with individual's daily travel for the whole population. These tours/trips can then be assigned to a transport network.

4.4.19 Most activity-based demand models are linked with static user equilibrium highway and public transport assignment models as in the standard models. There are also cases where activity-based demand models are integrated with dynamic agent-based assignment models. There is currently limited guidance on the use of dynamic assignments. Guidance for the standard assignment models can be found in TAG units M3.1 and M3.2 in the Guidance for the Modelling Practitioner.

Intra-household Interaction

4.4.20 The necessity or potential for carrying out joint engagement in activities can be considered when modelling activity generation and activity patterns, see the dashed line boxes in Figure 5. There are advanced activity-based demand models that include explicit model of joint travel and activities between members of the same households, for example, interactions when parents taking children to school Such models contain extra sub-components which model activities at household level and then joint travel activities involving multiple household members, and using those predictions to condition the individual activity pattern for each person in the household. The tour-level and trip-level model components should consider the fact that some tours involve multiple household members, while others do not. This will require a more complex framework and detailed data.

4.5 Application of Activity-based Demand Models

4.5.1 Table 2 shows a non-exhaustive list of activity-based demand model applications in transport policy and planning. This list only illustrates a few examples where activity-based demand models can be beneficial.

Table 2 Examples of Activity-based Demand Model Applications

Applications	Model Functionality
Socio-demographic dynamics	• Capturing travel pattern and changes as a result of socio-demographic dynamics • Changes in commuting patterns, such as telecommuters and 'work from home'
Road pricing	• Enhanced segmentation and explicit modelling of joint travel • Daily charging schemes

Applications	Model Functionality
Public transport	• Behaviourally consistent mode choice models that account for entire-tour constraints, e.g., fare capping, discounts and exemptions
Carpooling	• Explicit modelling of joint travel
Equity analysis	• Assessing and comparison of distributional measures of equity across groups

4.5.2 Transport for London, at the time of publication, operate an activity-based demand model of London. Examples of their model applications are listed in Table 3. This is intended as helpful information and does not provide requirements on how practitioners should implement their models in these circumstances.

Table 3 Activity-based Demand Model Applications (London Examples)

Applications	Model Functionality	Added Value
Rail demand analysis	Quantifying orbital and radial rail demand and identifying the main drivers of demand by journey purpose	The analysis was carried out using a wider range of journey purposes (compared to the standard model, this can be done easily without having to go back to the beginning of the model development to define journey purposes).
Connected autonomous vehicle (CAV)	Assessing the potential use of CAV in the future	Ability to model interactions between potential CAV users and public transport demand, by quantifying the threats and opportunities of CAV on public transport demand. An example of a threat is when captive users of public transport (e.g., non-driver licence holders) may be encouraged to use CAV. Opportunities arise as CAV can help solve the first and last mile accessibility challenges of public transport
Micro-mobility	Quantifying potential demand for micro-modes	Ability to identify trip stages where micro-mobility modes can promote the use of public transport modes.
Parking policy	Identifying individuals and their car use	The model can provide the level of car use by individuals and what they use car for, which allows practitioners to assess whether these car trips can switch to sustainable modes (public transport, cycling and walking)

Applications	Model Functionality	Added Value
Drivers of demand	Understanding key drivers of car use and barriers to switch to sustainable modes	The model can show where people live and where they go to perform their daily activities. For each car trip that individuals make, the model can show the individuals' affordability, journey time, access to public transport and cost that makes car an attractive option
Car journey to work/school policy	Identifying: • agents/individuals that make car journey to work/school and the work/school locations • the concentration of these journeys • whether these journeys can be made by using other modes	The model can test various incentives to encourage as many people as possible to switch to sustainable modes. This policy testing requires identification of agents, where they live, where they work, and their activities throughout the day
Road pricing	Identifying potential users (and purpose of travel) of the London congestion charging zone (CCZ) and the impacts of the daily charge on mode choice and air quality	The charge is a daily charge whereby drivers only pay once irrespective of the number of times they enter or cross the charging area, which will affect their choices throughout the day (e.g. activities, destinations, modes, and routes of travel).
Scenario quantification	Supporting policies, particularly, assessing the impacts and uncertainties of working from home on public transport demand.	The model captures the impacts of work location (home or out-of-home) on the location of other activities in the travel plan throughout the day and hence the resulting trip patterns and mode choices. It also quantifies the impacts on public transport demand based on various assumptions related to different types of London residents and non-London residents (e.g., age groups, life stages, income, work status, household compositions)

5. Technical Considerations

5.1 Introduction

5.1.1 This section focuses on key decisions required when considering the development of an activity-based demand model. The advice in this section is based on limited evidence and will be updated when new evidence become available.

5.2 Model Transferability

5.2.1 Activity-based demand models incorporate large number of components and include detailed individual and activity types. These models usually require large sample household surveys to estimate the full set of model parameters. These parameters include sensitivities to travel costs and temporal constraints.

5.2.2 The details of the model specification will determine the data required to estimate all model parameters. Careful consideration is required to estimate the sample size for collection of household activity-travel data needed to estimate a full set of activity-based model parameters.

5.2.3 Practitioners may consider three options when planning to develop activity-based demand models: **devise**, **adjust**, or **adapt** (SHRP 2, 2015). Whichever approach is chosen, practitioners must provide sufficient documentation that provides assurance of the approach and the ultimate validity and fitness for purpose of the model to provide for its use cases. See TAG unit M1.1 Principles of Modelling and Forecasting for the general expectations.

5.2.4 The **devise** approach refers to developing an entirely new activity-based demand model. This includes:

- specifying and designing the model,
- gathering new household activity-travel survey data and other data describing travel behaviour,
- developing various model components (such as activity generation, car ownership, destination, and mode choice),
- estimation of model parameters,
- transport supply network development,
- integration of model components, and
- model calibration and validation.

5.2.5 The **adjust** approach refers to the gradual development of an activity-based model in parallel to a standard model (or an existing model). Taking account of budget and resources constraints, practitioners may choose to move towards gradual development of activity-based demand models. An example is when existing network assignment models are combined with an enhanced demand models by introducing:

- a synthetic population; and
- activity generation estimation (such as replacing trip end / trip generation models in trip-based models).

5.2.6 The **adapt** (or transfer) approach refers to using an existing activity-based demand model developed elsewhere. The practitioner would pick up an existing model developed for another geography, incorporate this (sometimes called 'donor' model) into a full model system, then adapt and validate it using local data. This approach may not involve a re-estimation of all new model parameters.

5.2.7 There are cases where an activity-based models' parameters might be transferrable and applicable to other geographic regions. The spatial transferability of an activity-based demand model is supported when the theory behind the donor model is considered acceptable in the recipient jurisdiction and there is some evidence that the cultural and economic contexts are sufficiently similar.

5.2.8 Within this context, features can be added as required, and model parameters can be re-estimated or re-calibrated. Estimating model parameters from robust local data is preferred, in particular where there are local survey data available with an appropriate sample size. Otherwise, it is expected that the parameters from a model system estimated on a large sample size in a comparable region elsewhere can be suitable to explore some policy options, but the model should then be adjusted to match survey observations from the local region.

5.2.9 In order to use this approach, evidence is required to show that the make-up of the synthetic population, and the assumptions about activity-travel participation are valid for the new modelled area. The outputs of the adapted models should be validated using local activity-travel data. Guidance on validating activity-based model is discussed in section 5.5.

5.3 Data Requirements

5.3.1 A key stage in developing activity-based demand models is collecting the activity-travel data required to implement the model system. Models tend to be based either on travel diary data or time use data.

5.3.2 Table 4 presents key data types that should be considered for the development and applications of activity-based demand models. Practitioners should refer to TAG Unit M1.2 Data Sources and Surveys for guidance on available data sources for demand modelling, however, there is currently limited guidance on data sources for the purpose of developing activity-based demand models.

Table 4 Activity-based Demand Model Data Types, Applications, and Sources

Data Type	Application	Data Sources
Household travel diary	• Model parameter estimation for out-of-home activity characteristics • Travel Time Budget	National Travel Survey (NTS), Local household travel diary surveys
Time use surveys	• Parameter estimation for activity generation • Trade-off between in-home vs out-of-home activities • Working from home • On-line shopping • Activity sequences and scheduling • Daily activity-travel time constraint	UK Time Use Surveys
Demographic	• Synthetic population	UK Census data, mid-year population estimates
Land use	• Synthetic population • Activity generation and scheduling • Activity location choice sets	Regional land use data, Workplace data

5.3.3 Travel diaries are commonly available, at national and local levels, and have been most widely used, but analysed as a proxy for ‘non-home activities’ diaries. Respondents are asked to record, for each non-home trip destination, the main purpose of the activity at that location, along with information such as arrival and departure times, and mode of travel. For activity-based modelling and analysis, this information is then transformed into a non-home activity record, and used to calculate activity duration by subtracting the location arrival from the location departure time.

5.3.4 However, there are two important limitations to using travel diaries to develop activity-based models. Firstly, they do not capture in-home activities, such as home working, so do not provide a good basis for modelling in-home / out-of-home activity location trade-offs. Secondly, they typically only record one main trip purpose (or activity) at each location, whereas activity diaries, such as time use surveys, show more than one activity can be undertaken at each non-home stop. As a result, there is risk of underestimating out-of-home activity participation using travel diary data (Khorgami et al, 2010). Moreover, travel diaries usually only provide a limited range of trip purpose (activity) categories.

5.3.5 Conversely, activity diaries and time use surveys provide a much richer recording of the activities carried out at each location (both in and out of the home). There is typically a greater range of activity categories available, and respondents can record several sequential primary activities at the same location. Some surveys also allow for the recording of secondary activities, carried out in parallel with the primary activities. However, traditionally, the spatial resolution of activity diaries is not so detailed. If the model is used to address intra-household interactions (negotiating the use of the car or who drives the kids to school), additional data collection on these decisions and their logic is required.

5.4 Model Calibration and Validation

5.4.1 The diversity of possible agent-based implementations presents a challenge to provide guidance on their implementation, calibration, or validation. Agent-based methods for mode or route choice within dynamic transport simulation are very different from agent-based methods of household members' interactions within an activity-based demand model.

5.4.2 Evidence from operational activity-based demand models in the UK is currently limited. Similarly, there is limited experience in the implementation of agent-based choice methods within dynamic transport simulation models. Therefore, the principles of model calibration and validation in the current guidance can be implemented as a minimum.

5.4.3 The principles of demand model calibration in TAG Unit M2.1 Variable Demand Modelling can be applied to the development of activity-based demand models. However, some guidance may not be appropriate, for example, the illustrative parameters for destination and mode choice may need to be assessed and modified according to the choice modelling implemented in the activity-based models. Matrix estimation is also not a technique than may be employed in calibration as calibration is carried out at a more fundamental level (e.g. location choice or activity scheduling). Most importantly, these parameters will need to be calibrated, ideally by using available local data or new surveys. Sensitivity testing should be carried out to identify relative effects of various model parameters on the model results. Furthermore, it is important to conduct realism tests to ensure that the model's response to changes in inputs is realistic.

5.4.4 As shown in Figure 3 Section 2.4, the outputs from activity-based demand models can be assigned to the transport network using standard trip-based assignment methods or agent-based assignment methods. Whichever assignment methods chosen, the calibration and validation of assignment models should follow best practice outlined in TAG units M3.1 and M3.2 in the Guidance for the Modelling Practitioner.

5.4.5 Further discussion on calibration and validation for agent-based and activity-based demand models is outlined in the following sub-sections.

Calibration

5.4.6 Calibration of an agent-based method is often focused on the calibration of agent decision making parameters and validation carried out on the collective behaviour of the resultant system.

5.4.7 There remains limited academic guidance on the calibration of agent-based methods, across any domain. However, there are a range of approaches that may be considered. Some approaches have strong theoretical underpinnings and others lean more on computational exploration with derived validation from aggregate performance.

- **External agent behaviour calibration**. Recent literature has focussed on the external calibration of a given agent parameter using standard statistical methods (Horl et al., 2019). A choice model is calibrated externally, using survey data to form a decision-making model that is then transplanted into an overarching agent-based method. This process is robust as the agent decision making can be calibrated and then validated in isolation first, then further confidence built by validating how this parameter behaves when part of an agent-based simulated system. For example, a mode choice agent behaviour may be created using a discrete choice model, calibrated on survey data. This model may be inserted into agent(s) who then perform mode choice within an agent-based assignment simulation and the resultant traffic flows may be validated against traffic volumes.

- **Directed or undirected parameter search**. Some agent-based calibration approaches involve directed or undirected exploration of agent parameters with pre-defined performance target criteria. These parameters may not be measurable in real-world data or have any underlying theoretical underpinning. This exploration may be a random walk (Axhausen et al., 2016) or make use of novel algorithms in machine learning, for example reinforcement learning (Sert et al., 2020). Similar to external agent calibration, confidence in overall model performance is often derived from the ability of the model to validate against system level criteria.

- **Machine learning methods**. The directed and undirected calibration approaches capture a diverse range of possible techniques. It is worth noting that modern research in machine learning offers possible solutions that may bridge the gap between machine learning and robust standard statistical calibration (Aboutaleb et al., 2021).

5.4.8 It must be recognised that the calibration of agent-based models risks overfitting, in particular when the last two methods above are used. Care must be taken to ensure the resulting models can be interpreted and are not used as black boxes, as well as testing the models for the reasonableness of their responses under very different conditions.

5.4.9 As with agent-based methods, calibration of an activity-based demand model should focus on the representation of agent decision making parameters and validation carried out on the resulting collective behaviour.

5.4.10 Some activity-based demand models might be transferred, where parameters and functions estimated in another area are calibrated to local survey data (see Figure 6).

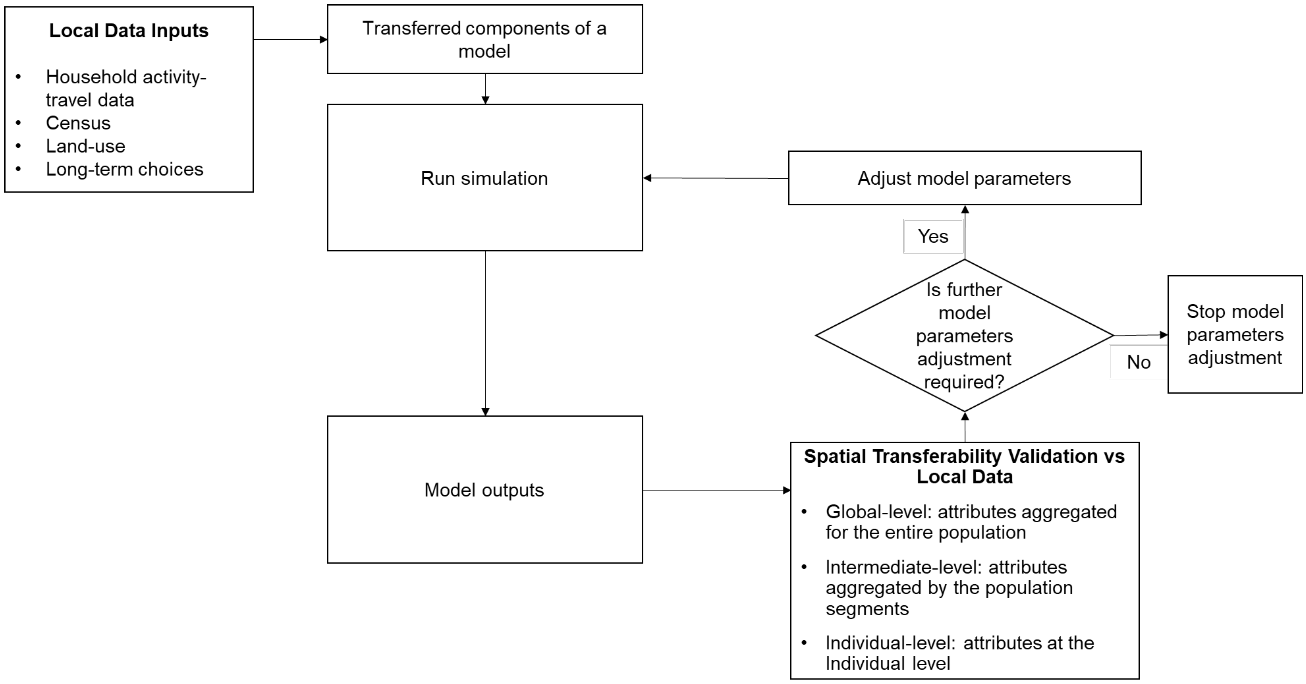

Figure 6 A Conceptual Framework for Validating and Adjusting Transferred Activity-based Demand Models

Validation

5.4.11 The validation criteria and guidelines for agent-based and activity-based models will still need to be developed. In the meantime, the same validation criteria and guidelines applied to the standard models should be used. Agent-based methods output macro system level data that may be compared to real-world or other model outputs, such as travel times, mode shares, or traffic volume counts. However, there are important differences that must be considered.

5.4.12 Evidence is required to show that the activity-based demand models are capable of reproducing activity-travel behaviour of people in the study area. Validation of the activity rates, temporal properties, spatial properties, and structure of activity sequences (activity schedules) of activity-based demand models is required. New surveys to provide appropriate data may be required. Further research is needed in this area.

5.4.13 The validation of model outputs may be undertaken at many levels. The detail of the implementation can be used to compare global, intermediate, and individual outputs to real-world data or other models. The existence of outputs across a spread of scales may be both an opportunity and a challenge to validation. The opportunity is that diverse model outputs may be compared, and the challenge lies in the weighting of this diverse outputs (for example, their relative importance to each other, in the context of a given use case). The simulated outputs for each household or individual can be compared with the observed attributes, whilst a more aggregate comparison of model outputs is more relevant in the context of strategic transport modelling.

Global Validation

5.4.14 Aggregate, global validation is derived validation, where the parameters of the agents are not validated themselves, but their resultant (often aggregated) behaviour is. Total vehicle kilometres or global mode shares are examples of this. The extraction of model response elasticities is possible and can be used to assure the level of sensitivity to interventions against known or modelled elasticities.

5.4.15 Global validation can also be derived from the resultant activity sequences of the activity-based demand model. The overall pattern of activities, properties such as start times and durations, should be validated against aggregate survey data.

5.4.16 Additionally, these activity sequences provide aggregate information on trip numbers by mode, demand by time period, and travel purpose. These trip / tour level data can be validated just as for standard models (such as trip length distributions), as outlined in TAG Unit M2.2 Base Year Demand Matrix Development.

Intermediate Validation

5.4.17 Intermediate validation often makes use of spatial or sub-population differences in agent populations to understand how specific groups of agents behave in the model. In essence this is a subset of aggregate, global validation and may involve the same measurements carried out across different subsets. For example, traffic or passenger count comparisons as for standard models discussed in TAG units M3.1 and M3.2 in the Guidance for the Modelling Practitioner.

5.4.18 As another example, Table 5 presents activity-based model properties and relevant validation tasks, statistical tests, and data sources (see Drchal et al., 2015; Drchal et al., 2016; Roorda et al., 2008).

Table 5 Framework for Validating Activity-based Model Outputs

Model Property	Validation Task	Statistical Tests	Data Sources
Frequency of activities, tours, and trips	• Compare the distribution of activities/activity-episodes for each activity type • Compare the distribution of number tours by type • Compare the distribution of number of stops per tour • Compare the number of trips	Kolmogorov-Smirnov (K-S) statistic Root Mean Square Error (RMSE)	Activity diaries
Activities in time	• Compare the distribution of start-time and duration for activities/activity-episodes for each activity type • Compare the joint distribution of start-time and duration for activities/activity-episodes for each activity type	Kolmogorov-Smirnov (KS) statistic Root Mean Square Error (RMSE)	Activity diaries
Activities in space	• Compare activity distributions in space for each activity type • Compare distribution of distance to activity locations by activity-start time	Kernel-based method Pearson's χ2 statistic Kolmogorov-Smirnov (KS) statistic Root Mean Square Error (RMSE)	Travel diaries
Structure of activities	• Activity count: Compare activity counts within activity schedules • Activity sequences: Compare distributions of activity schedule subsequence as n-grams profiles	Pearson's χ2 test statistic Pattern analysis techniques	Travel diaries

Individual Validation

5.4.19 Individual validation makes use of data that may be benchmarked against a unique agent. It is the lowest level of aggregation and is concerned with using novel data sets, with high spatial and temporal resolution, such as individual GPS traces. Examples focus on validating individual choices from the agent-based methodology, for example mode and route choice against a GPS trace which shows real-world exhibited behaviour (Kozlowska et al., 2020). Similar to intermediate validation, care should be taken to select meaningful agents, whose attributes and behaviour are of significance to the scheme under consideration. As these are almost illustrative, subjective and open to selection bias, these should carry less weight than global and intermediate validation.

5.4.20 It is likely that a combination of global, intermediate and individual measures will be appropriate. Care should be taken with individual measures to ensure that they are weighted appropriately. In the context of a strategic agent-based method using a synthetic population, it may be that there is significant heterogeneity in agents. Agents that are statistically representative and important for a given use case should be treated as such in the validation hierarchy. The validation of an agent-based method against aggregate statistics does not mean that all its various other modelled outputs may be taken as validated.

5.4.21 The flexibility of the methodology requires consideration of the specific use case in question, and the interactions modelled. This is to ensure that the validation is appropriate and sufficiently robust for the use case. Since no prescriptive answer can be given, a series of questions are suggested to help shape how this may be approached:

- Are the use case specific agent behaviours modelled?
- What level of aggregate validation has been achieved? Is there confidence in overall aggregate response and is there available data for realism testing?
- If sub-population distributional impacts are being explored, has sufficient intermediate / individual validation been carried out? If not, can derived agent-behaviour be calibrated and validated externally?

5.4.22 In all cases, the validity or lack of assured validity of the model used for the drawing of any conclusions relating to specific behaviour of individuals should be transparently reported. The risk of drawing of conclusions that are potentially false, due to the potential lack of validation of more detailed aspects of the model, if that detail is key to the question, must be mitigated.

Model Response

5.4.23 Similar to any standard model, realism testing should be used to assess if model response is realistic to changes in inputs. However, in practice, it may be difficult to find real-world data for some of the relevant scenarios that are being explored. Realism tests are discussed in TAG Unit M2.1 – Variable Demand Modelling.

5.5 Other Modelling Considerations

Simulation Variation

5.5.1 Activity-based demand models simulate the decision processes of individuals listed in generated synthetic populations, as random draws from choice sets (activity choice, destination choice, mode choice, and so on). These models use simulation techniques, typically Monte Carlo methods, to simulate choices. Therefore, the outcome of a model run includes some components that are stochastic and special measures are required to compensate for this and to assure reproducibility of the model results.

5.5.2 The stochastic nature of activity and tour generation in the activity-based demand model brings variability to the model's results. There are other elements of activity-based models that can affect the level of variability, such as the population sampling and traffic assignment method.

5.5.3 There are ways of compensating for Monte Carlo variability. One way is to fix the random number seed in the functions used by the program to generate random numbers. This is known as frozen randomness. While this can be complex for a large number of choices, this results in the program generating the same sequence of random numbers for successive runs, which means that outcomes will only vary according to changes in inputs. This ensures stability from run to run but at the cost of representing only one possible outcome from the model. For some applications it may be preferable to do many runs and average the aggregate results to account for simulation variation, and/or compare the difference in outputs based on different seed values to understand the level of variation in model results. The disaggregate outputs can be used to produce distributions and statistical confidence intervals in addition to average values for activity-based model results.

5.5.4 It should be noted that the standard models produce single-point forecasts, given fixed inputs. When this is considered unrealistic, scenario planning is recommended. Activity-based model outputs may be presented as a range of outcomes, or distributions indicating a degree of uncertainty in the model results.

5.5.5 The use of stochastic processes means that convergence to equilibrium would be different from that in deterministic models. Agent-based implementations may, for example, employ a co-evolutionary algorithm to achieve a stochastic user equilibrium (Axhausen et al, 2016). Even when this is achieved, there may be ongoing dynamics below macro measures of stability (such as utility, traffic volumes or journey times on individual links) and care must be taken to ensure there is sufficient stability in each of the phenomena of concern.

Convergence and Equilibration

5.5.6 The stability of model outputs is essential and changes to demand or supply should lead to reasonable changes in model outputs. Similar to the standard variable demand model, an activity-based demand model includes an assignment stage to provide travel cost information to the demand model. The assignment stage must be adequately converged, as this is necessary to achieve a good level of convergence between the assignment model and the demand model. Most transport models need two equilibrium models: one main loop between demand and supply, and a smaller loop between route choice and route cost in the assignment model. It is essential that an equilibrium solution between demand and supply is obtained. Iterative feedback processes of demand and supply should be included in activity-based model systems to ensure that the models are achieving convergence to an equilibrium, or at least a stable condition.

5.5.7 Although the transport system in reality will not necessarily be in an equilibrium state, the equilibrium solution in the models provides a consistent basis on which to compare forecasts. Failure to achieve acceptable convergence to equilibrium can lead to highly misleading results.

5.5.8 In practice, finding exact equilibrium usually requires disproportionate resources, so it is usually found within tolerance standards, as set out for the standard models in TAG units M2.1, M3.1 and M3.2 in the Guidance for the Modelling Practitioner. Guidance on model stability and convergence from these units can be applied to activity-based demand models and associated assignment models, however, the stochasticity effect of these models should be considered.

5.5.9 Section 5.4 discusses the calibration and validation of agent-based and activity-based demand models and the challenges associated with extracting insights from model outputs that have not been validated. The use of stochastic processes within an agent-based model means that even when aggregate stability may be present, there are likely to be underlying dynamics which are fluctuating and changing. The stability of model outputs is essential, particularly when they are used in scheme appraisal to support business cases. Practitioners must ensure that changes to demand or supply should lead to reasonable changes to model outputs, which are the true and meaningful insights, rather than due to underlying dynamics of the modelling processes.

5.5.10 When using activity-based demand models and/or dynamic agent-based assignment models, practitioners must be able to demonstrate model stability and convergence, particularly if these models are proposed to be used in the economic appraisal of business cases.

Model Run Times

5.5.11 Agent-based implementations generally make use of sampling techniques for efficiency, simulating a sub-sample of the true population. Consideration must be given to the trade-off between improved precision by increasing the sample size versus the computational cost of doing so. The sampling decision must also consider the dynamics of the phenomena being modelled as some transportation use cases, for example DRT may require higher samples due to potentially smaller number of users and the complexity of their decisions (Kuehnel, et al 2022).

5.5.12 The complexity of model design, demand and supply feedback, and the level of convergence required will influence the run times. Both standard model and activity-based model run times vary greatly. In both cases, assigning the demand to the network can be computationally time-consuming. The decision of where and how agent-based interactions are implemented greatly influences the computational complexity and therefore run times.

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7. Further Reading

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