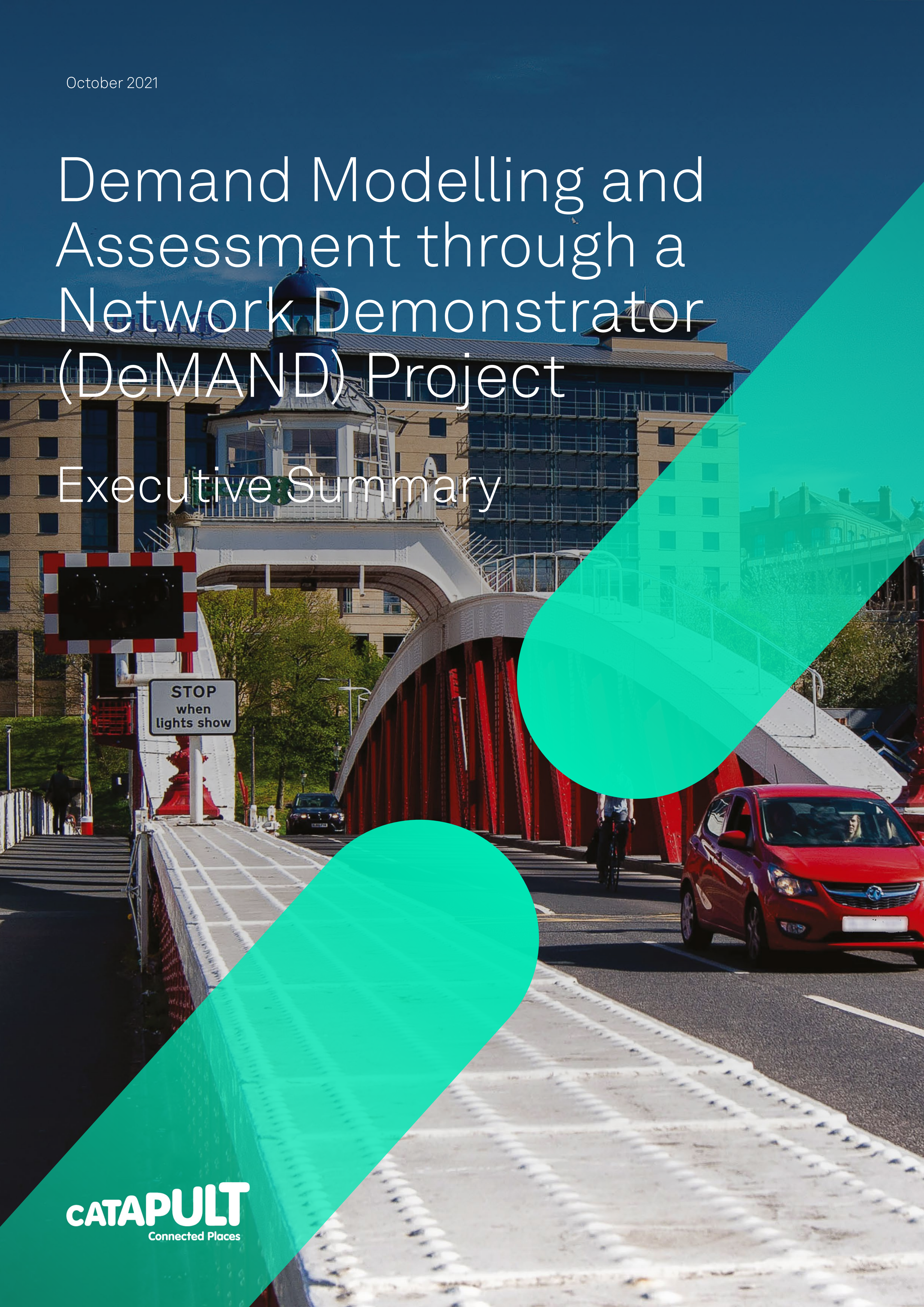
October 2021

Demand Modelling and Assessment through a Network Demonstrator (DeMAND) Project

Executive Summary



Connected Places

Executive Summary

The “Demand Modelling and Assessment through a Network Demonstrator” (DeMAND) project focuses on the development of a new methodology to assess the demand for the introduction of New Mobility Services in urban areas.

Multimodality and attitudes towards sharing will affect how people will travel in the future and demand modelling must move away from the traditional division of transport modes.

Travel behaviour is gradually getting more difficult to predict, hence the increased complexity of travel demand models to fit modern lifestyle, and the increased demand to include autonomy and flexibility. As a direct consequence, we can notice diverse travel patterns as well as the reduced availability of private transport for certain population groups.

The foundation study for the DeMAND project, the “Business Case for new Mobility Services: Demand Modelling Tools”[1] project identified some key changes to demand modelling approach:

- End-to-end users’ journeys;
- Multimodality, where private on-demand services are integrated to the public transport ecosystem;
- The ability to represent Mobility as a Service’ integration with public transport systems; and
- The variability over 24 hours of all travel patterns to identify demand at different times of the day and for a large-scale area in order to capture all commuting patterns (even beyond the administrative boundaries of a council).

Drawing from these learnings, the DeMAND[2] project focuses on the development of a new methodology for an urban demonstrator, a data-driven agent-based model which uses an activity-based approach to derive complex travel patterns from mobile network data aggregated at trip-chains level.

The agent-based model is built using the open-source platform MATSim, a multi-agent micro-simulation model[3]. The demand modelled is optimised individually for each agent, as a complete temporal dynamic description of the daily demand.

1 https://cp.catapult.org.uk/wp-content/uploads/2021/01/Business-case-for-New-Mobility-Services_Demand-Modelling-tools_Executive-Summary.pdf
2 funded by the Grant Funding Agreement between the UK Department for Transport - Office for Science and Connected Places Catapult (2019/2020)
3 https://www.matsim.org/

Generation of a synthetic population using Mobile Network Data

The DeMAND model represents a synthetic population of nearly 650,000 agents (individual people) replicating the transport choices and preferences within Tyne and Wear (population 1.136 million in 2018) in the North East of England. Each agent bears the socio-demographics characteristics, spatial information, and daily activity schedules using the anonymised and aggregated mobile network data (MND) sourced from O2Motion (Telefonica).

The metropolitan area was chosen as a case study for its greater propensity for using the public transport and to identify ways to improve current level of service with the introduction of ‘on-demand’ shared modes (restricted to demand responsive transport for this study) when running in integration with a multimodal public transport system.

Daily travel plans are built using an activity-chains dataset derived from MND aggregated at trip-chains level. A data exploratory framework built in python was used to accelerate the analysis of the MND and assign purpose and mode of travel to each intermediate trip.

The methodology allows to assign agents a new segmentation by purpose (home, work, leisure/shopping, education, and freight with local and long distribution) and mode of transport (walk, cycling, bus, metro, rail, car). Travel demand is then assigned to six time periods divided in AM peak (07:00 to 10:00), inter peak 1 (10:00 to 13:00), inter peak 2 (13:00 to 16:00), PM peak (16:00 to 19:00), off peak 1 (19:00 to 22:00) and off peak 2 (22:00 to 07:00).

Road and Public Transport Network

The model includes the road network for the North East of England, and a multimodal public transport network with 844 bus services (of which 250 in rural areas), 230 rail services connecting the North East with the rest of the UK. Cycling lanes and segregated walking/cycling paths are also part of the network. Walking and cycling are not present as a stand-alone choice. However, the time spent in walking and cycling is included in the access and egress time to the public transport.

Agents' Preferences and Choices

Agents' preferences and travel choices are derived from an online survey combined with a stated preference survey.

A questionnaire collected data from 1,500 residents in Tyne and Wear to gauge their interest in on demand shared mobility services. Demand Responsive Transport was chosen as preferred mobility service to cover first/last mile, enabling modal shift and encourage residents to use fewer private cars in favour of public transport, as a greener option.

The questionnaire covered: current travel behaviour; perceptions and attitudes of travellers; socio-demographic characteristics and the Stated Preference survey section.

Survey results highlighted:

- Respondents were hesitant about sharing a journey with strangers: concerns on perceived comfort (68%), privacy (67%) and safety (62%);
- The majority of people (66%) are unlikely to consider a shared transport mode, with 17% of respondents likely to consider it. Younger residents aged under 40 (26%) and those with household incomes of over £60K (25%) are most likely to consider shared transport (but only for leisure and shopping purpose). This implies different social rules compared to sharing a busy tube carriage or bus. Early adopters of the shared service are car drivers:
  - 35% are 'Older less mobile car owners[4]' (defined as mature adults with mobility difficulties that travel less compared to other car owners);
  - 24% are 'Town and rural heavy car use[3]' (defined as working age, higher income, but less educated in rural/urban areas with high level of car ownership and car travel, 13% of UK population);
  - Knowing the route increased the perception of control and safety among potential passengers;
  - Users in Tyne and Wear will be keen to walk around 10 minutes to reach the pickup point if this helps in streamlining the service and reduce times in diversion because of other passengers on board.

4 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/395091/climate-change-segmentation-review.pdf
3 https://www.matsim.org/

Discrete choice modelling

The stated preference survey collected information on travel habits and attitudes towards shared mode for 1,500 residents (0.5% of the entire population of Tyne and Wear). Evidence from the survey has been used to estimate Agents' preferences and choices in the model in the form of MATSim scoring for the daily travel plans. Each travel plan carried out by an agent is scored against marginal utilities linked to the activity and the mode of travel used.

Two nested logit models were developed for two groups of purposes (i.e. work/study and leisure/shopping) for incomes below £60k and above £60k. The parametric models have been developed using the open-source Python package Biogeme[5]. The coefficients used for these models, including the value of time for shared modes can be transferable to other modelling uses in the future.

Digital twin for Tyne and Wear

The DeMAND MATSim model represents a digital twin of Tyne and Wear and the North East of England for an average day in 2018. The synthetic population built using activity-chains from Mobile Network data allows you to see the door-to door travel patterns from residents (simple and complex tours where starting zone and end zone are the same), as well as all the outbound and inbound journeys from people not living there, that are normally difficult to capture with traditional survey methods.

The model represents how people move and their transport choices and preference allow us to test a variety of mobility services, either in integration or not with the current public transport system. Identifying the demand and catchment area for mobility services is a straightforward application of the model, which allows us to plan and integrate services for bus, rail or aviation and to understand the possible early adopters depending on the characteristics of the service.

Local and long distribution of goods

In the model, freight movement linked to logistics activities represent the 5% of total agents, of which 95% are made defined as local distribution, where goods are distributed to residents or internally within the region. Long distribution travel patterns are linked to long haul logistics and is often happening overnight. These agents are not directly involved in the assignment of users to DRT, however contributes to build up traffic in the road network. The higher temporal granularity allows the identification of anonymised and aggregated travel patterns, working practices in both local and long distribution of goods without the need to collect data from logistics operator.

5 https://biogeme.epfl.ch/index.html

Uptake of shared mobility

The study and the modelling developed suggests that early adopters of shared mobility services would be car drivers with a higher propensity in using their cars, either because of underlying mobility issues or because they are living in rural areas and heavily reliant on private cars. In both cases it is recommended to set up a service that would be able to suit both the young early adopters and the aging population in Tyne and Wear and the surrounding areas.

Further improvements

For future model development, the implementation of dynamic agents' preferences will allow us to add a Demand Responsive Transit (DRT) with scoring and an updated value of time for shared mobility services. This will allow to test various scenarios with DRT in integrations with the public transport system, as previously tested for the Innovate UK funded MODLE project (*https://cp.catapult.org.uk/project/mobility-on-demand-laboratory-environment-modle-project/*).

The base year model 2018 was set up using the standard scoring function in MATSim with coefficient from the stated preference survey. The code generated to implement the new scoring function was developed alongside the new coefficients derived from the stated preference survey. The next step could involve the implementation of the new scoring method, where a higher value of time is applied to activities which are time constrained.

The DeMAND model was run for 100 iterations, in 6 weeks using 17 CPU, 256 Gb RAM and 1Tb of hard disk. It is recommended to run the simulation using a higher number of cores or cloud computing in order to run the model within acceptable time frame.

The comparative analysis of the initial results of the base case model has indicated that agents have shorter travel times compared to real travel times in the network, when trips are in urban areas. The inclusion of traffic signals or the integration with another platform will better represent traffic delays and allow the model to reach a better performance.

Assessing Sustainable Transport Solutions for Rural Mobility

The DeMAND methodology can only be applied to urban areas, although looking at travel patterns, Tyne and Wear is closely connected to the nearby rural counties, Northumberland and Durham, which have very similar travel patterns. This bond creates extra pressure on the urban areas and an extra demand that Tyne and Wear will need to cater for when planning for more sustainable mobility solutions. Following the completion of DeMAND, another project was developed, to look at this relationship with nearby rural areas.

The Assessing Sustainable Transport Solutions (AsSeTS) for Rural Mobility project[6] funded by the collaborative grant funding agreement between Department for Transport and Connected Places Catapults (2020/2021) assessed the transferability of the DeMAND methodology to rural areas and improved the knowledge base around demand for new mobility services, using a data-driven approach.

The AsSeTS for Rural Mobility project identifies and suggests ways to remove barriers which prevent New Mobility Services (NMS) being commercially viable in rural areas by:

- Using data-driven approaches to understand typical daily travel patterns; and
- Identifying new mobility services which can be deployed commercially, and those that will be likely to require on-going financial support, in order to provide socially necessary services.

6 https://cp.catapult.org.uk/project/assessing-sustainable-transport-solutions-for-rural-mobility-executive-summary/

Rural Innovation for Sustainable Environments (RISE) for Decarbonising Last Mile Road Freight

During DeMAND and AsSeTS for Rural Mobility projects, it was identified that rural areas (traditionally carbon intensive communities) were driving the increase in last mile deliveries, with local logistics accounting for 95% of road freight regionally. This growth in carbon intensive last mile road freight deliveries in rural areas risks compromising the Government ambitions for 'net-zero' greenhouse gas emissions.

In order to change to new sustainable mobility services for goods and support the decarbonisation of road freight, it is necessary to develop viable business, environmental and social cases for new logistic practices. The RISE project[7] will assess the connection between consumer behaviour and transport demand for last mile deliveries. RISE is using agent-based and emissions modelling of integrated transport to understand the increased efficiency of urban freight transport, leading to fewer transport miles.

7 Rural Innovation for Sustainable Environments for Decarbonising Last Mile Road Freight project, funded by the UK Department for Transport under the collaborative Grant Funding Agreement (21/22) between the Office for Science and the Connected Places Catapult

Glossary

New Mobility Services (NMS) are new modes of transport linked to the sharing economy and the development of new ways to reach customers (i.e. Ride hailing, ride sharing, car share, bike share, carpooling, micro mobility, including e-scooters), enabled by disruptive technology and innovative business models that facilitate effective sharing of mobility resources. NMS emerged to contribute to more sustainable and climate-friendly mobility solutions. New-Mobility-Services are very often designed with the concept of shared mobility in mind, where users are willing to share, either vehicles (i.e. micromobility such as e-scooters or e-bikes) or a trip with other users.

Demand Responsive Transport (DRT) is a shared mode of transportation that adapts to the demands of its user groups, often accessible via a digital platform or mobile app.

In the questionnaire developed for this study, DRT was described to residents as "when you can use cars, buses or minibuses when you need to and share a lift with other people who are travelling in the same direction. It does not run on a timetable like traditional public transport. It does not have a fixed route and can be either door-to-door or corner-to-corner (when the DRT pick up is a short walk from the house).

Mobility as a Service (MaaS) constitutes the integration of various forms of transport services into a single mobility service accessible on demand. Booming demand for more personalised transport services has created a market space and momentum for MaaS. (Source MaaS Alliance)

Agent- Based Modelling creates a synthetic population of agents to understand complexities in human behaviour. Agents are entities with their own behaviour, preferences and activities to fulfil. When it comes to modelling mobility, agents can be either users of the service (static agents whose plan consist of a sequence of trips or activities) or vehicles (dynamic agents with no prior predefined activities). Agent-based model can be developed using trip ends (where single trips are available from one zone to another) or activities, where trips are organised in chains.

Activity Based Modelling is a modelling tool where activities are generated using household surveys, mobile network data or other data source and provide information on purpose, mode of travel and duration of travel (i.e. going to work, shopping, leisure activities, escorting children to school, etc.).

Synthetic Population is designed to resemble a real-world population with respect to sociodemographic characteristics and spatial information. In agent-based modelling, each agent in the population is associated also with daily activity plans.

Spatial Granularity depends on conventional zoning system adopted by the Office for National Statistics:

- **Output Areas (OAs)** - the smallest geography for which 2011 Census data are available, with an average resident population of approximately 300 people;
- **Lower Super Output Areas (LSOAs)** - groups of OAs, with an average resident population of approximately 1,600 people;
- **Middle Super Output Areas (MSOAs)** - groups of LSOAs, with an average resident population of approximately 7,800 people;
- **Wards** - administrative boundaries at 2011 Census, with an average resident population of 6,500, it is also so far available for the following higher level geographies:
- **Local Authorities Districts.**

Mobile Network Data: Mobiles phones generate "events" as they communicate with the national cell network. These events are collected on an anonymised basis for analysis and aggregated at a suitable spatial granularity (LSOA, MSOA, LA district). Each event is linked to a persistent yet anonymised user ID, a timestamp and the cell ID of the cell that recorded the event.

Mobile Network Data available commercially are normally provided at MSOA level, which however is not granular enough to capture the complex travel patterns that might derive from residents. LSOA level is the smallest granularity that can be used with anonymised and aggregated MND to comply with GDPR.

Trip: a one-way course of travel with a single main purpose (National Travel Survey).

Tour: a round trip, from an origin to a destination and back to the origin.

Trip chains: a series of one or more "links", carried out by the same person for different purposes, within the given time period, regardless of the length of pauses between trips (National Travel Survey)

Trip-chain MND dataset: retains information on the full door-to-door journeys during the 24 hours. Patterns indicate how many users in the network have that specific combination of trips. All intermediate trips indicate where and when the trip occurred for an aggregated number of users. However, no purpose and mode of travel is available since trip-chains are aggregated directly from the events captured from the Local Area Cells (LACs).

Contents

1 Introduction

The foundation study, "Business Case Modelling for new mobility services: demand modelling tools" (Connected Places Catapult, 2019), highlighted that New Mobility Services have been primarily promoted by a technology-driven market, leading to disruptions within the more rigid public transport system.

Mobility services operators do not follow a consistent approach in the activation of these services. This can create barriers to sustainably introducing Mobility as a Service - a customer-centric seamless integration of multiple mobility services, which ultimately aims to provide an integrated door-to-door service encompassing a 'one stop shop' for planning, booking, paying for and taking multi-modal journeys.

Specifically, many of these services concentrated on the optimisation of the on-demand mobility service without taking in consideration a deep analysis of the users' needs, current travel behaviour and possible requirements to induce a behavioural change in people's decisions. The main barrier for the launch of commercially sustainable Demand Responsive Transport (DRT) services seems to be the identification and attraction of the right level of demand. The DRT service needs to be viable and commercially sustainable during weekdays (*Franco et al.*, 2020), as it was already demonstrated that DRT are successfully introduced and attract enough demand when run during weekends (i.e. trials run in Kent and Essex County Council).

1.1 Background

The foundation study in 2019 revealed that in order to identify demand and support the operation of a flexible shared service in a virtual testbed environment, a strategic transport models' approach would be needed and should include:

- **Multimodality:** to overcome the traditional division between highway assignment and public transport assignment, so the approach should allow the model to represent the interaction between on-demand shared services and fixed schedules public transport services;
- **Shared services:** where no route or timetable (or both) is available to define the service; and
- **Activity-chains:** for a service provider it is important to identify areas with latent demand, with a comprehensive understanding of real travel patterns and not just the number of trips between one area and another.

Drawing from the learnings from the "*Business Case for New Mobility Service: Demand Modelling Tools*" Project , the Demand Modelling and Assessment through a Network Demonstrator (DeMAND) project focuses on the development of a new methodology to model demand for new mobility services, promoting a data-driven agent-based model which uses an activity-based approach.

8 Business-case-for-New-Mobility-Services_Demand-Modelling-tools_Executive-Summary.pdf (netdna-ssl.com)

1.2 Objectives

The DeMAND project aims to understand current travel habits and attitudes towards shared mobility, as well as developing a prototype agent-based model to assess demand for New Mobility Services (NMS). Specific project objectives are to understand the:

- Attitude of people towards sharing and how the uptake of NMS and Mobility as a Service (MaaS) is affected by the propensity of people to share; how the value of time changes when on demand services are used and how this will affect the costs in the model;
- Willingness to pay and value of time for different population segments: users' behaviour is modelled when presented with a range of conventional and new transport options. Users' choices in the model change and so will the coefficients/elasticities for NMS, which need to be tailored to the specific mode of transport;
- Development of an Agent Based Model using an activity-based approach for an average weekday;
- Methodology, data requirements and processes developed to build an agent-based model for the purpose of assessing demand for NMS, including evaluation and full documentation of the work carried out to allow for scalability and transferability in line with industry needs;
- Recommendations for the next steps to provide the foundations for Department for Transport's (Dft) Transport Analysis Guidance (TAG) on the generation of agent-based models to the transport modelling industry.

The urban demonstrator is set up as a large-scale Agent Based Model (ABM) that will allow to test, on a first instance, the introduction of a Demand Responsive Transport services that will integrate with existing mobility services (either private or public transport services).

1.3 Case study

The location of the prototype is Tyne and Wear in the North East of England (***figure 1***). With the lowest rate of car ownership in the UK, Tyne and Wear users are already relying on an efficient public transport system, where the underground (Metro) is operating alongside a balanced presence of major bus operators in the metropolitan area.

The DeMAND project collected available datasets for the purpose of modelling demand for New Mobility Services. Other datasets were generated during the project with the purpose of understanding residents' current travel behaviours and attitude towards sharing.

Transport North East and Nexus, the Passenger Transport Executive for the Tyne and Wear, both supported the project in kind with the provision of public transport usage data and insights.

Figure 1: Location of the case study for the DeMAND project

A scenario was designed to introduce a DRT in newly developed areas and in areas where public transport has a comparatively lower level of service, creating transport poverty conditions (in case the user has no access to a car) or an increased dependency on the availability of private cars. However, project constraints only allowed for preliminary analysis to identify demand for the service.

1.4 Model definition

The DeMAND project is an urban demonstrator, defined by a data-rich environment where legacy datasets will need to be integrated with new data source generation. Specifically, Mobile Phone Network Data was used to generate travel demand.

The agent-based model in this project estimates individual agent behaviour and predicts the entire day's activity-travel schedule. It's a bottom-up approach, where modelling disaggregate agent behaviour leads to emergence of global behaviour. As such, the model encompasses both a highway assignment and a public transport assignment at the same time.

> The prototype modelling tool is a large-scale agent-based model with activity-based approach to forecast travel behaviours for new modes of transport, developed in the open source platform MATSim.

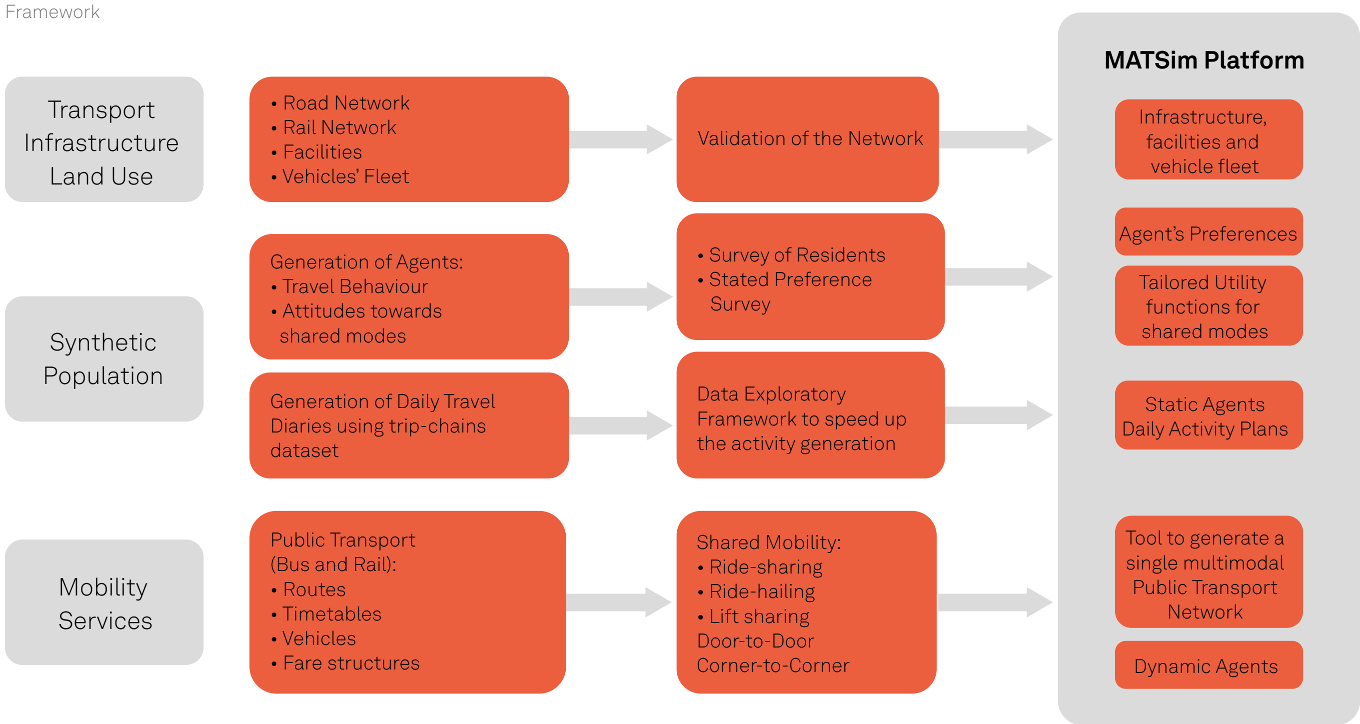
The model represents an average weekly day in March 2018 for 24 hours, because the study aims to understand users' choice under different modes of transport available in normal (undisturbed) conditions.

Traditionally, agents are generated by travel diaries which also provide activity schedules. For DeMAND, a synthetic population is generated using anonymised and aggregated mobile network data at higher spatial and temporal granularity. This allowed Connected Places Catapult to obtain daily activity plans that were more complex and articulated (from 1 to 21 trips in a day for a single agent) and to capture a much wider sample. Using this methodology, 647,768 agents were generated.

These agents are either doing Return journeys (when start and end are the same, 583,222) and the additional demand coming from outbound and inbound journeys (Not Return journey, 275,838), where journeys are defined as a combination of different trips in the same day.

The additional demand is not removed because they contribute to create congestion in the network. However, in MATSim it is possible to reduce their ability to change mode or travel patterns. This additional demand also includes 5% of journeys which are linked to logistics, either linked to local or long-range distribution.

Figure 2:
DeMAND modelling Framework



2 Measuring attitudes towards shared and emerging mobility services

The DeMAND project focused on the development of a new methodology to assess the demand for the introduction of New Mobility Services (NMS) in urban areas. The methodology can be developed further to assist decision makers to appraise Mobility as a Service (MaaS) schemes and emerging on-demand mobility services, changing appropriately data requirements.

Drawing on learnings from previous work developed by the Transport Systems Catapult and others, the most appropriate methodology to build the prototype is that of a data-driven agent-based model which uses an activity-based approach. Tyne and Wear in the North East of England was chosen as a case study, to be able to test how shared modes (restricted to demand responsive transport on a first instance) are integrating with a multimodal public transport system.

As part of the preliminary work to build the agent-based model (ABM), an online questionnaire was developed to collect data from residents in Tyne and Wear (population 1.136 million in 2018).

This chapter reports on the evidence collected during the survey of residents and the attitudes towards shared and emerging mobility services.

2.1 Summary of method

An online questionnaire was carried out to gather insights from 1,500 residents in Tyne and Wear with the aim to establish their:

- Current travel behaviour including detailed information on one recent trip;
- Attitudes that potentially influence mobility behaviour and decisions;
- Attitudes towards new mobility services; and socio-demographics.

In addition, questions were asked that would allow respondents to be allocated to one of the Department for Transport's (DfT) transport user segments[9].

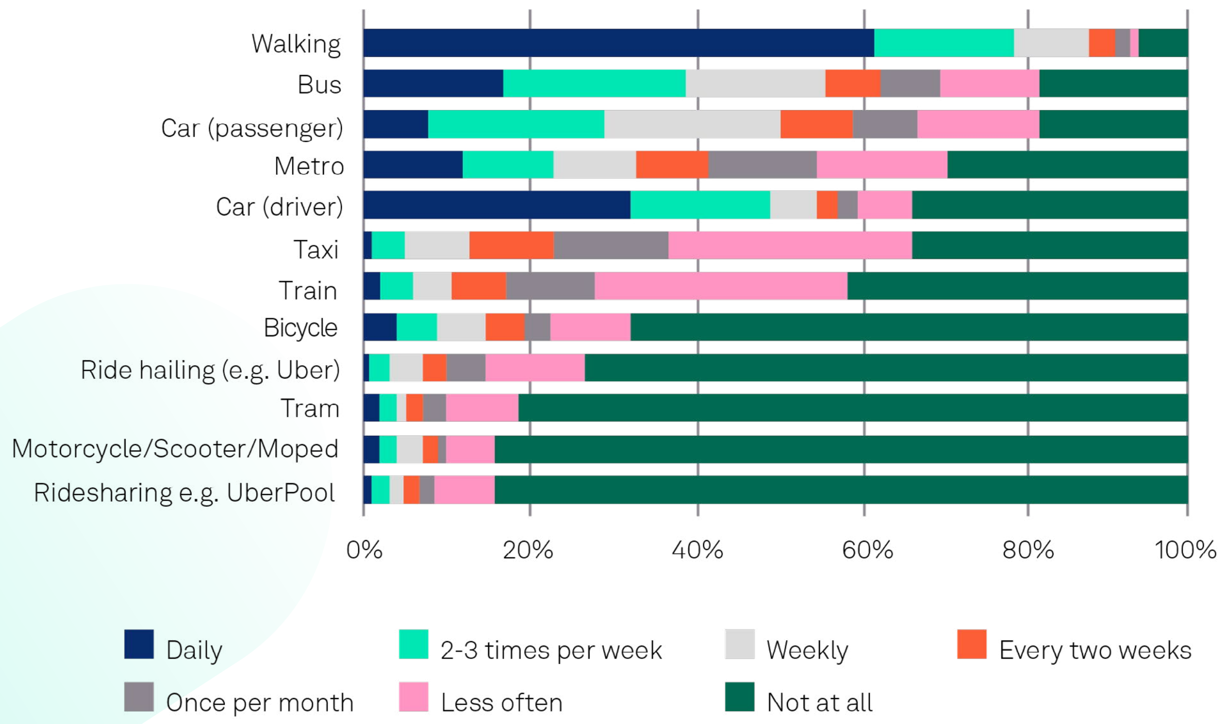
Participants were selected from an online panel of UK residents. The survey responses were weighted to adjust back to a representative profile of adult residents of Tyne and Wear by age, gender and car and van ownership levels, as summarised in ***table 1***.

Table 1: Table of achieved surveys versus weighted profile

		Achieved	Weighted
Gender	Female	58%	52%
	Male	42%	48%
Age	16-29	22%	24%
	30-39	27%	16%
	40-49	23%	14%
	50-59	16%	16%
	60+	13%	30%
Vehicle Ownership	None	27%	36%
	One	44%	40%
	Two+	29%	24%

9 https://www.gov.uk/government/publications/climate-change-and-transport-choices-segmentation-update

Figure 3: Modes of Transport used in Tyne and Wear (source: Survey of residents, DeMAND project, 2019)



2.2 Key findings

Sharing Transport

- The majority of people (66%) are unlikely to consider a shared transport mode, with 17% of respondents likely to consider it. Younger residents aged under 40 (26%) and those with household incomes of over £60K (25%) are most likely to consider shared transport
- The largest concern with regards to sharing transport was around sharing space with others and how that affects perceived comfort (68%), privacy (67%) and safety (62%)
- Respondents largely agreed that shared transport brings the potential for less congestion (67%), that it's better for the environment than driving (66%) and that it's cheaper than running a car yourself (66%)

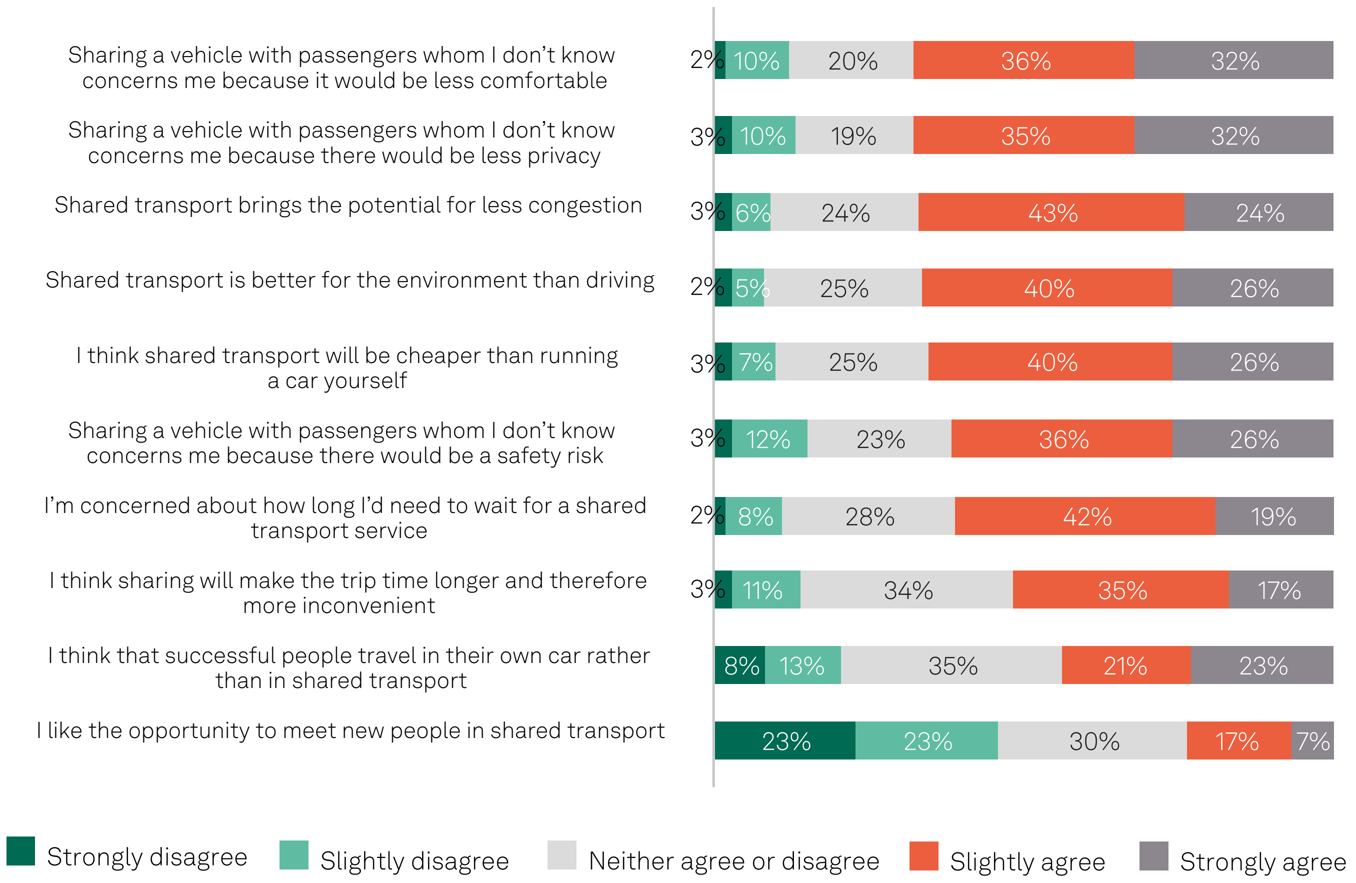
Two segments were found to have higher propensity to share transport - 'Older less mobile car owners' (35%) and 'Town and rural heavy car use' (24%), when using the transport user segments from the Transport Choices Segmentation Study (2018).

Those two segments represent the 22% of population nationally.

The 'Older less mobile car owners' is highly likely that are already using the public transport and will look at shared mobility as an integrated service with PT that will allow them to move around more freely, if configured as a first/last mile service.

The 'Town and rural heavy car use' are either one car household or mature adult that would stay mobile for longer without the need to have a car of their own.

Figure 4: Attitudes to sharing (source: DeMAND project, 2019 – Base 1,500 respondents)



Base: All respondents (1500)

Younger residents aged under 40 are more likely to consider shared transport (26%) compared to those aged 40+ (12%). Those with higher incomes are more likely to consider shared transport. For those earning annual household income of under £30k, only 14% were likely to consider shared transport. However, 25% of people with household incomes of over £60k are likely to consider shared transport.

When asked specifically about car sharing to work, a higher proportion (23%) agreed they would like to do this, suggesting that for the journey to work some people may see more value in sharing than as a general transport choice. The appeal of car sharing to work is greater for those in social grades ABC1C2 (27% in agreement) than for those in social grade DE (18%). Those earning less than £30k per annum agreed with this less (17%) than those in higher income brackets of £30k to £89k (33%). Those with children in the household agree with this more (35%) than those without (16%), and respondents with a disability agree with this more (32%) than those without (21%).

The Environment

- Despite media coverage and political standpoints, respondents seem largely indifferent with regards to environmental issues, with 36% stating they are neither interested or uninterested, and 39% responding as not actively thinking about nor ignoring their carbon footprint

Safety, risk and openness to change

- People consider public transport to be safer more so during the day (70%) than at night (39%)
- Forty percent of respondents agrees that they are the type of person who is always looking for new ways to do things, though a larger proportion prefer sticking to the things they know (60%)
- Overall, 34% are willing to take risks but this is correlated to age and level of education with those aged 20-40 more prepared to accept risk (41%) and those with a higher degree (49%) and first degree/diploma (40%) also more accepting of risk
- Across all respondents, 29% have made a significant change to their transport choices in the past three months with younger people and those with higher levels of education more likely to have done so

Current journeys and transport usage

- Bus was the most frequently used mode of public transport in Tyne & Wear with 17% using it daily and 56% using it at least once per week
- Just over a quarter (28%) had used ride hailing services such as Uber in the past three months, with 7% using it at least once per week. Usage of ridesharing such as Uber Pool is lower with 15% accessing these services in the past three months
- From a given weekday in the previous week for a randomly selected trip from the respondents:
  - The most common reasons people travelled were to go shopping and to go to work
  - A half (51%) of car journeys were of five miles or less with the mean journey distance approximately nine miles
  - The mean cost of a journey was approximately £5 for those whose main mode of transport was any vehicle (not walking or cycling). This includes 16% who claim that their journey was free

Results from the survey of residents fed into the stated preference section described in next paragraph.

2.3 Design of a Stated Preference Experiment for Modelling Traveller Choice Behaviour towards Shared Transport

A key requirement of the project is to promote deeper understanding of mode choice behaviour with particular regard to the introduction of new mobility services based on ride sharing. This led to the development of transport mode-specific utility functions (through discrete choice modelling) which were used in conjunction with an activity-based model using mobile phone network trip-based and trip-chain data, to gain insights in users' travel patterns.

The utility functions provided marginal effects, elasticities and willingness-to-pay parameters for the most influential transport service level and socio-economic factors of travel behaviour. Moreover, individual attitudes towards shared mobility and their related socio-economic determinants were also analysed.

When the questionnaire was administered, in September 2019, private hired vehicles were available in Tyne and Wear However, shared mobility services, such as Uber Pool (when users going in the same direction share a ride for a lower price) were not active. Respondents provided an hypothetical answer based on the scenario described to them. The aim of the SP survey is to establish value of time and willingness to pay for these services, so that marginal utilities in the model can be tailored around this new mobility service.

2.3.1 Stated Preference survey

A Stated Preference (SP) survey was carried out to enable the development of choice models and utility functions that simulate the potential reaction of Tyne and Wear users to the introduction of ride sharing services.

Stated Preference surveys have been widely applied in the areas of marketing and travel demand modelling to analyse consumers' evaluation of products and services based on multiple attributes, when there are hypothetical choice alternatives and new attributes.

The SP survey design process was broken down into the following main steps:

- Identifying socio-economic, attitudinal and alternative-specific potentially important attributes;
- Development of the questionnaire to collect data on the aforementioned attributes;
- Design of an SP experiment (experimental design) to elicit individual preferences towards actual and hypothetical choice alternatives;
- Pilot study;
- Implementation of Internet and/or presential surveys.

2.3.2 Stated Preference experiment design

The methodological foundation of a Stated Preference study is the experimental design. The basic stage of an experimental design process is the identification and refinement of stimuli, which involves primary decisions on the list of alternatives, attributes and relative levels of variation.

In this study the choice response approach was adopted, so that the individual behaviour (the selection of an option in the SP survey scenario) can be interpreted as a decision-making process based on an underlying unobserved continuous random variable (latent variable), called *utility function*, which represents, for a generic alternative, the utility perceived by a single user depending upon a series of alternative-specific characteristics.

Table: 2: The SP experiment choice set.

Alternatives	**Car**			**Public Transport**				**Shared Transport**				**Active Travel**	
Attributes	Twalk (min)	Tin-transport (min)	Cost (••)	Twalk (min)	Twait (min)	Tin-transport (min)	Cost (••)	Twalk (min)	Twait (min)	Tin-transport (min)	Cost (••)	Tin-transport (min)	Route Type
High Level	3	15	4	14	6	25	1.3	2	10	21	2.5	25	Dedicated lane
Low Level		10		7	3	15			5	14	1.7	15	Normal road

2.3.3 Stated Preference findings

The use of stated preference experimental design and random utility modelling to analyse and simulate travel behaviour within Tyne and Wear yielded interesting insights into the socio-demographic and trasport service factors of travel mode decision-making, with particular regard to individual preference towards ride sharing. In more detail, the following main findings are worth highlighting:

- The in-vehicle time impact on individual utility is far higher for active travel (probably for the physical effort required) and shared transport;
- Walking and waiting time unit variations have similar effects upon utility;
- Sensitivity to transport cost decreases (and value of travel time saving rises) remarkably when the household yearly gross income exceeds the threshold of £60,000;
- Dedicated lanes providing vehicle traffic-free paths for active travellers do make active travelling more appealing;
- There are significant inertia effects, since individuals, when faced with hypothetical mode choice scenarios, tend to be influenced by their habits. In particular, in the shared transport case, if a decision-maker has used most frequently ride sharing over the recent months, they are more likely to choose shared transport, within the SP experiment, than people normally preferring other travel modes. This means that ride sharing is able to gain customer loyalty;
- In general, individuals traditionally needing full control over their trips, such as self-employed people and freelancers moving for work purposes, carers (for non-leisure trips) and disabled are less oriented towards ride sharing;
- Finally, some model-based simulations have pointed out that a corner-to-corner DRT, requiring to walk a bit more than usual in exchange to no deviations en route and more efficient service (lower in-vehicle times and costs), can potentially make shared transport more competitive and pricing policies against car use more effective.

2.4 Utility Function Development for Shared Mobility Services

This section describes the results obtained by the two nested logit models generated for work/study and leisure/shopping. Coefficients were derived for the model-based value of time per person for every travel time component, trip purpose and household yearly income band.

Transport mode-specific utility functions and travel behaviour models for the Tyne and Wear area were developed adopting Stated Preference (SP) experiments and random utility modelling, during the preliminary work to build the agent-based model (ABM).

Specifically, an online questionnaire was developed to collect data from 1,500 residents in Tyne and Wear, which covered the following key-areas:

- Current travel behaviour;
- Perceptions and attitudes of travellers;
- Socio-demographic characteristics; and
- Stated Preference Survey (SPS).

The Stated Preference survey developed for the DeMAND project asked participants to consider hypothetical transport mode choice scenarios, which included new mobility services based on ride sharing, and to declare their preferred alternative. The hypothetical choice scenarios were based on an urban trip. Furthermore, the SP experiment was designed around two trip purposes, i.e. reaching the work/study place and others (leisure/shopping/personal business), as well as a set of four transport alternatives: private car, public transport (i.e. bus/metro), shared transport and active travel (i.e. bike/scooter). In order to provide useful insights into travel mode decision-making, given the resource and cognitive constraints, the choice games were built using:

- Five transport service attributes;
- Three travel time main components (walking, waiting and in-transport time);
- Travel cost; and
- Availability of dedicated lanes for active travel.

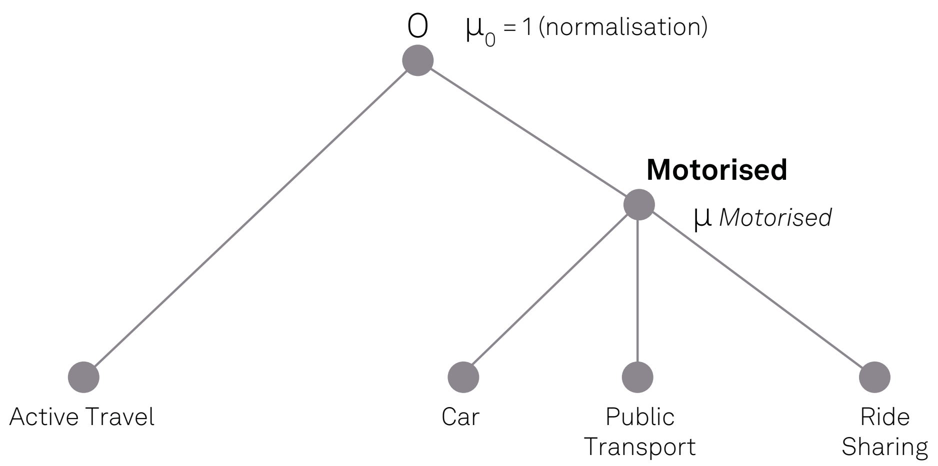
The data from the on-line survey were used to develop two Logit models, one for the work/study purpose and another for leisure, shopping and personal business. The model specifications included transport service and socio-demographic explanatory variables.

Table 3: Mode shares from simulations with the logit models considering average conditions for the car parking cost

Modes of Transport	Work/Study Share	Leisure/Shopping/Personal Business Share
Car	56%	63%
Public Transport	24%	23%
Shared Transport	7%	5%
Active Travel	13%	9%
All Modes	100%	100%

The resulting estimated coefficients (marginal impacts on mode-specific utilities) and values of travel time savings were analysed and interpreted. Moreover, the models were used for simulation and scenario analysis exploring the potential market penetration of a recent innovation in the ride sharing industry that implies higher walking times in exchange for a more efficient service.

Figure 5: Nesting structure for the work/study and leisure/other models



2.4.1 Analysis of the travel time saving values from model estimation

The value of travel time saving (VTTS) or value of time (VOT) represents the amount of money a person would be willing to pay for a unit decrease in travel time. The model-based VOT values for the DeMAND project were estimated for both trip purposes and each income level dividing the considered time component coefficient by the travel cost parameter. ***Tables 4 (a-d)*** present the model-based value of time per person in pounds/hour for every travel time component, trip purpose and household yearly income band (< £60,000 and ≥ £60,000). The income bands were determined after extensive experimentation with a number of specifications at the modelling stage, which revealed that only above the limit of £60,000 the annual household income has a significant (statistically) impact on travel cost sensitivity.

Tables 4: Estimated values of travel time savings from the work/study and leisure/other models

a) VOT per time component (work/study) - Income < 60

Time Component	Time Coeff.	Cost Coeff.	VOT (£)
Tin_transport_Car	-0.0364	-0.424	5.15
Tin_transport_PT	-0.0333	-0.424	4.71
Tin_transport_ST	-0.0885	-0.424	12.52
Tin_transport_AT	-0.0735	-0.424	10.40
Tout_of_vehicle	-0.0548	-0.424	7.75

b) VOT per time component (work/study) - Income ••60

Time Component	Time Coeff.	Cost Coeff.	VOT (£)
Tin_transport_Car	-0.0364	-0.21	10.40
Tin_transport_PT	-0.0333	-0.21	9.51
Tin_transport_ST	-0.0885	-0.21	25.29
Tin_transport_AT	-0.0735	-0.21	21.00
Tout_of_vehicle	-0.0548	-0.21	15.66

c) VOT per time component (non-work/study) - Income < 60

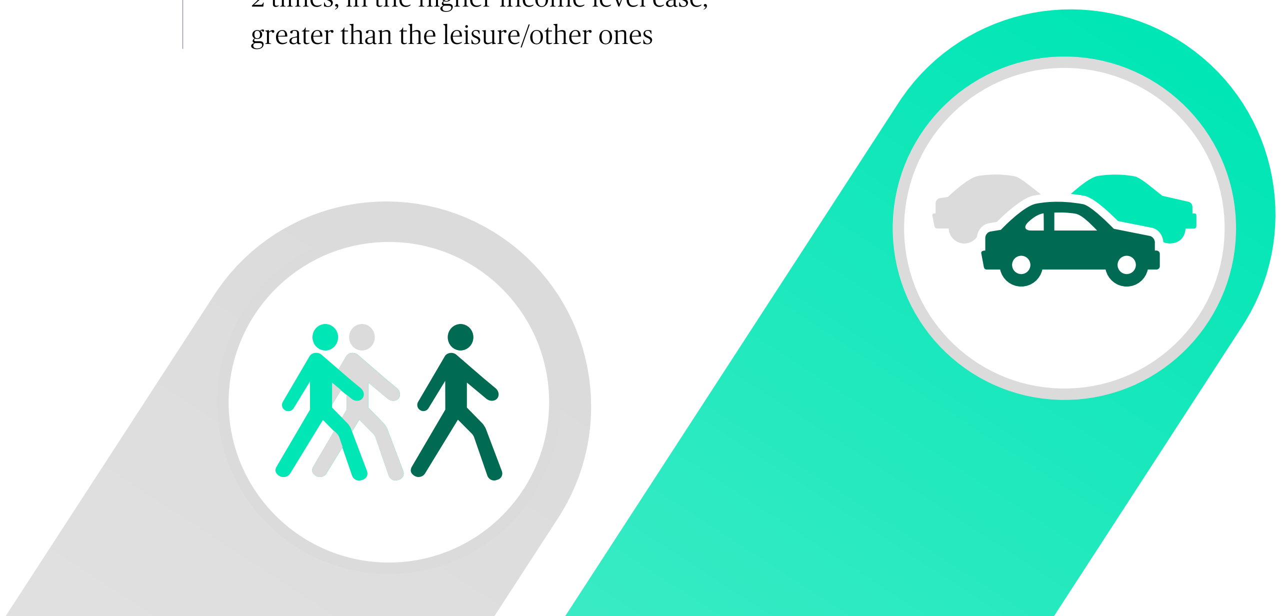
Time Component	Time Coeff.	Cost Coeff.	VOT (£)
Tin_transport_Car	-0.0253	-0.606	2.50
Tin_transport_PT	-0.033	-0.606	3.27
Tin_transport_ST	-0.0856	-0.606	8.48
Tin_transport_AT	-0.0659	-0.606	6.52
Tout_of_vehicle	-0.053	-0.606	5.25

d) VOT per time component (non-work/study) - Income ••60

Time Component	Time Coeff.	Cost Coeff.	VOT (£)
Tin_transport_Car	-0.0253	-0.371	4.09
Tin_transport_PT	-0.033	-0.371	5.34
Tin_transport_ST	-0.0856	-0.371	13.84
Tin_transport_AT	-0.0659	-0.371	10.66
Tout_of_vehicle	-0.053	-0.371	8.57

As emerges from ***Tables 4 (a-d)***:

- Higher income level values are around 2 times the lower ones (precisely, 2 times in the work/study case and 1.6 times in the leisure/other case)
- Work/study values are, on average, 1.6 times, in the lower income level case, and 2 times, in the higher income level case, greater than the leisure/other ones
- The value of out-of-vehicle time (walking and waiting) is around 1.5-2 times the public transport and car in-vehicle time values, which is fairly in agreement with the relevant literature (*Wardman*, 2004)



3 Generation of a synthetic population using Mobile Network Data

In the DeMAND project, the demand for travel is generated using two Mobile Network Datasets, trip-based origin-destination matrices and trip-chains dataset for an average weekly day in March 2018

Travel demand is usually derived from household surveys and travel diaries, where participants are asked about typical travel habits and patterns for different purposes of travel and different time of the day. This method provides rich information on travel behaviour and choices made by travellers, however, is strongly dependent on how accurate the respondents are and the survey design (i.e. preventing mental fatigue, avoid lengthy questionnaire, etc). The development of surveys and travel diaries is time consuming and samples size is linked to the availability of respondents. As a direct consequence, the use of the traditional approach to identify demand for travel may be limited for the development of a large-scale ABM.

Door-to-door users' journeys, which reflects people's travel patterns, are captured using anonymised and aggregated mobile phone network data, provided by O2 Motion (Telefonica), in order to generate a realistic demonstrator for urban mobility, the demand for travel is generated using:

- Origin Destination Matrix accounting for 995,689 trips
- Trip-chains Dataset 578,098 trip-chains for a total of 647,768 Agents

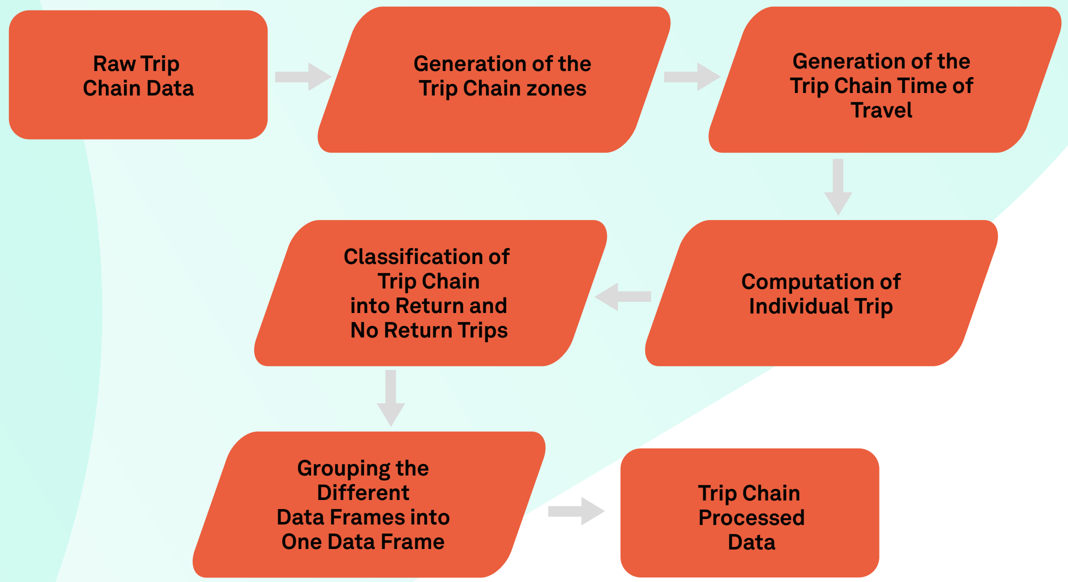
3.1 Daily travel patterns

3.1.1 Mobile Network Data: Trip chains

The MND aggregated at trip-chains level was created for the IUK funded MODLE project[10] upon Connected Places Catapult request (now commercially available from O2 - Telefonica) to study travel patterns and model mobility services. The dataset retains information on the full door-to-door journeys during the 24 hours on an average weekday. All intermediate trips indicate where and when the trip occurred.

Two mobile network datasets (trip-chains and OD matrices) were acquired for the North East of England. The use of MND at trip-chains allowed to represent complex travel patterns from areas where no recent or limited amount of data is available. In ***figure 6***, steps to pre-process the raw trip-chain dataset is shown.

Figure 6: Method for Pre-processing Trip Chains Data



10 https://doi.org/10.1016/j.tra.2019.09.038

3.1.2 Data exploratory Framework

The mobile network data used in this study provides different sets of users' information, which include OD matrices, Frequency matrices, Trip- chains dataset. The trip chain datasets do not provide the full information of the users journeys such the purposes of the trips and the transport mode used during each individual trip. The generation of the daily activity plans has been enhanced using a Data Exploratory Framework, developed by Connected Places Catapult, to accelerate the analysis and make the process transferable to other case studies. This technique identified the first leg of each individual journey of trip chain data from the OD matrix using the locations (i.e., starting zones and end zones), times of journey and the average number of trips completed. By using this method, we assigned purposes and mode of transport (i.e., road/train) to each individual trip chain data.

Once the trip chain is processed it provides the purpose and mode of travel used by the user. However, more data is required to overcome the lack of information on purpose of travel and mode of travel. Since purpose of travel from mobile network data is derived from the frequency of trips in a certain location over an extended period of time (usually four weeks of data), most of the trips' purposes are labelled as "other". Hence, land use data and locations of points of interest is used in combination with MND. These facilities include locations of the schools, businesses and retails.

This allows to provide a more detailed information about the users' locations during the journeys, and further data fusion operations were carried out to identify additional purposes and modes, such as school trips, shopping, logistics and travelling by metro, rail or bus.

The trip-chains data set includes information on 647,768 agents for an average day. The daily travel plan table is made of 578,099 rows for 68 columns and covers from 1 trip until 21 trips in a day. Each travel pattern corresponds to a group of agents that are travelling in the same combination of zones and in the same time period.

The sample is divided in groups of individuals with similar daily activity patterns, based on high level characteristic, such as number of trips they have in a day.

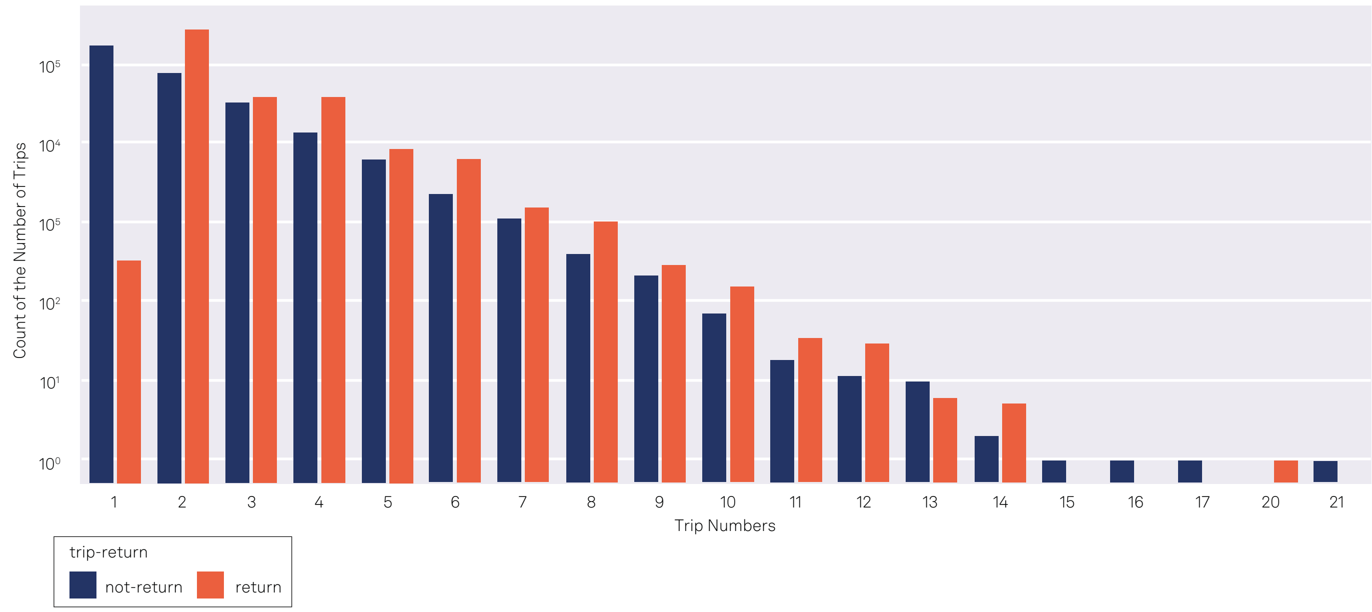
The 51.6 % of the trip-chains are simple tours with residents leaving home and going to work every day. The majority of residents during the day travel for leisure/ shopping activities and only during peak times purpose is associated with commuting. Residents made up the 95% of the sample. They are most likely to have simple tours (2-trip chains) with some of them doing more complex tours (up to 4/5 trips in a day).

The additional demand linked to freight distribution and logistics activities can be distinguished in local and long haul logistic .

Only 5% of the sample is made of freight distribution trips, of which 95% is represented by local distribution. These agents are not customers for the DRT, however, are included in the model to create realistic traffic conditions.

Figure 7: Travel patterns for the population in the North East of England

Distributions of user trip based on the trip number



At the end of the process nine purpose of travel where assigned and these were matched with activities.

It should be noted that the activity-based demand model can only estimates activities that can be generated directly using mobile network data only.

If other journey purposes need to be included, an alternative demand model should estimate the number of activities that users make, the time profile and location of each activity. For example, activities such as "Work" coincides with the trip purpose "Commuting" as specified in DfT's TAG Unit M2.1 (Variable Demand Modelling) , however, "Employer's business" is difficult to identify using only MND as data input.

At the end of the data fusion process, activities generated were work, home, leisure, education, logistics (divided in long haul and local distribution).

3.2 Generation of Agents

In the DeMAND model, agents are generated to best reflect the population characteristics in the region. To establish which dataset was the best fit and in order to assign the different attributes to the agents generated, an analysis of the MND data has been carried out and compared with available Census data (age, gender, income).

The socio-demographic information provided in the Telefonica MND covered 633,015 MND users. Among them only 20% were classified by the MND provider. Looking into this subset, the distribution across the age groups provided by MND, was analysed. Although there are differences in the categories from MND for the younger and elderly groups, we can observe that similarities are present in certain age groups such as 20-29 and 30-39, however younger groups are well underrepresented (0.1% vs >10%) and elderly (65+) female are overrepresented (14.35% vs 7%). For that reason, in the simulation of agents, two different age and gender distributions were adopted.

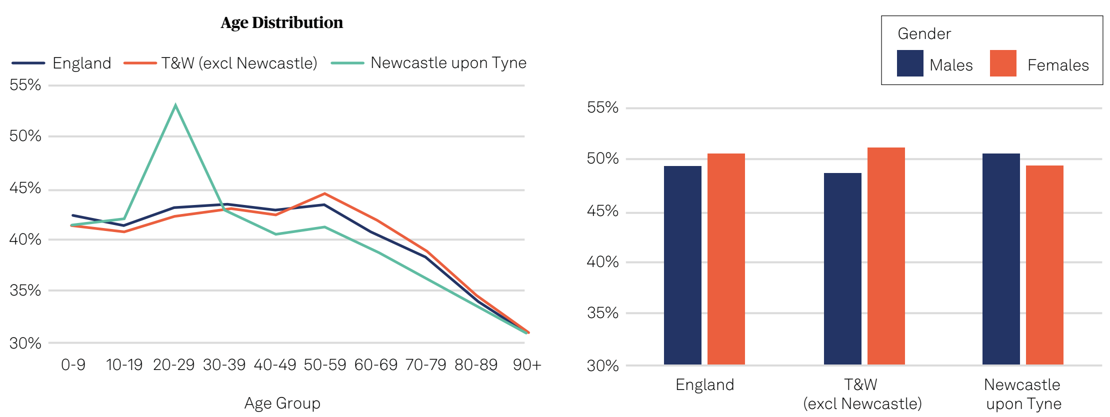


Figure 8: Age distribution (left) and Gender (right) for three different geographical areas, namely England, Tyne and Wear (excluding Newcastle) and Newcastle upon Tyne

Generally, MND demographics were in line with the Census data related to the Tyne and Wear, however, Newcastle did show a different demographics mainly driven by the presence of two large universities, with age and gender split different from the rest of the metropolitan area. MND tend to be best suited to reflect recent and rapid variation in population, but in this case Census data were best placed to reflect the population main characteristics. Following this phase, population attributes (age, gender, income) were assigned to the agents using a Montecarlo distribution.

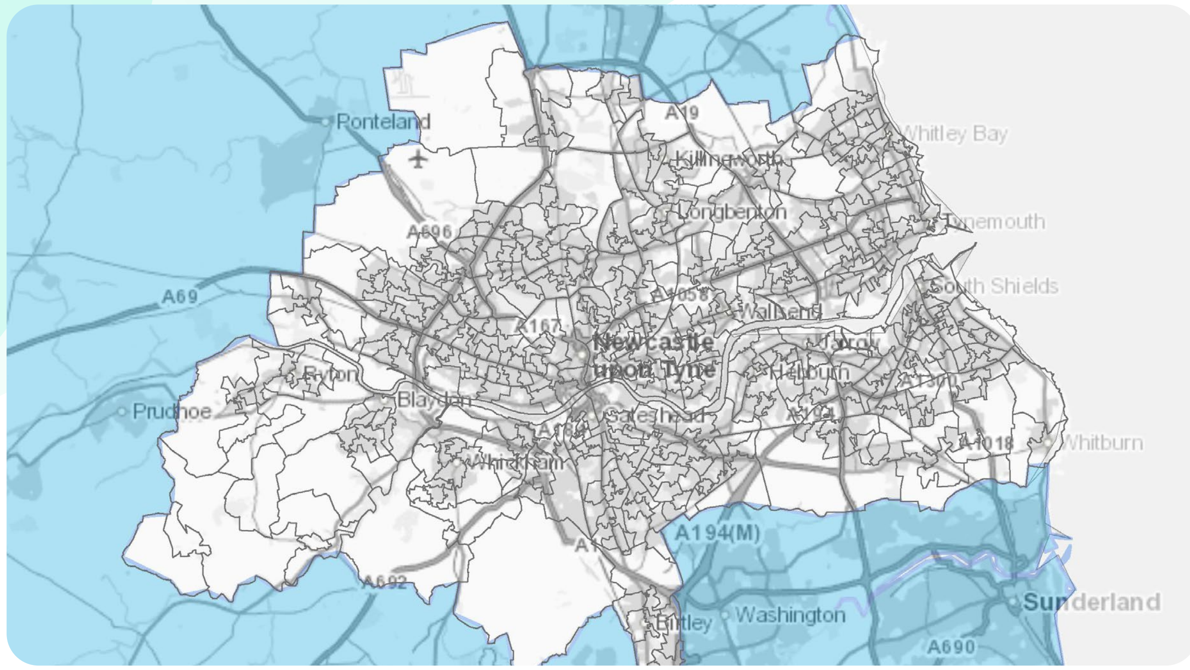
4 Agent based Model Development

The prototype modelling tool is a large-scale agent-based model with activity-based approach to forecast travel behaviours for new modes of transport, developed in the open source platform MATSim.

The prototype modelling tool is a large-scale agent-based model with activity-based approach to forecast travel behaviours for new modes of transport, developed in the open source platform MATSim.

MATSim[11] is used as a tool to build a microscopic representation of the current travel behaviours and habits. The aspiration is to build and calibrate a behavioural model with (in future phases) forecasting capability to answer "what if" questions.

The model generates agents with individual settings and daily travel plans for each agent.



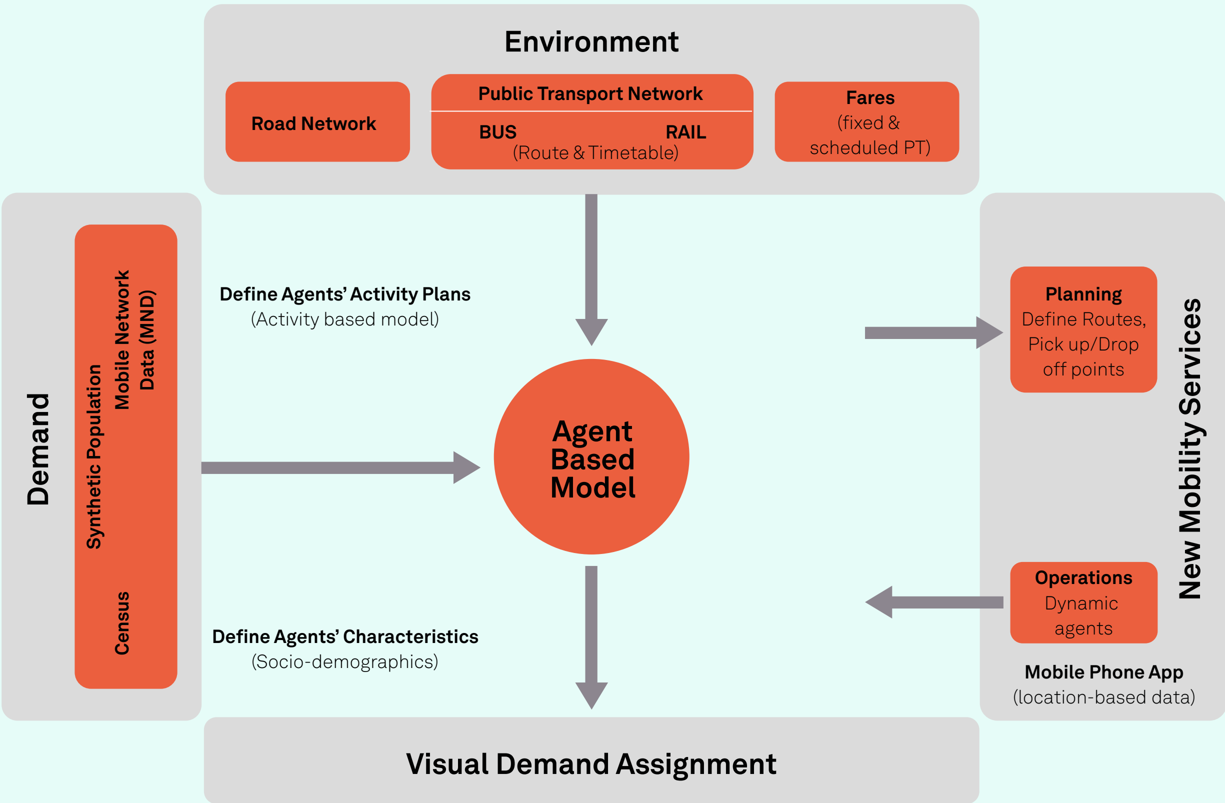
11 Multi-Agent Transport Simulation https://www.matsim.org/

4.1 Model data framework and key features

Agent-based models can rely on a wider set of parameters associated to agents' preferences, choice/scoring and trip-chains; hence ABMs can achieve a higher realism compared to traditional transport models.

As summarised in ***figure 9***, the ABM was built using publicly available data. The model includes a multimodal public transport network. The network and facilities have been imported using Open Street Map. The public transport network was imported from the publicly available Traveline Database, which provided routes and timetables. Rail services were downloaded from Association of Train Operating Companies. Bus stops and train stations are loaded from the National Public Transport Access Nodes (NaPTAN) database from Department for Transport (UK). Average fares structure was generated using fares from PT operators.

Figure 9: Agent-based Model data framework (source: Franco et all, 2020)



As for traditional models, all depends on the data available to validate such realism, but for MATSim the element that definitely differs from traditional model is the ability to represent trip-chains and combined trips which we have sourced/acquired from MND. The generation of a synthetic population using mobile network data is an innovative approach which has been implemented and explored by the Connected Places Catapult for the first time during the Innovate UK funded project Mobility on Demand Laboratory Environment (*Franco et a*l, 2020).

Feature	DeMAND Agent-based model
Model Base Year	• Weekday AM peak (07:00 to 10:00) • Weekday Inter-peak 1 (10:00 to 13:00) • Weekday Inter-peak 2 (13:00 to 16:00) • Weekday PM peak (16:00 to 19:00) • Weekday off-peak 1 (19:00 to 22:00) • Weekday off-peak 2 (22:00 to 07:00)
Modelled areas	Area of interest: Tyne and Wear Model extends to North East at lower granularity
Zone system	998 zones in total: • Tyne and Wear (534 zones at LSOA level) • North East (142 zones at MSOA level) • 322 Local Authority Districts (LADs) in England • Wales and Scotland as onew zone
Network coverage	All road network included (strategic and local)
Demand segmentation	• Segmentation by purpose of travel: *outbound home-based work (OB_HBW)* *bound home-based woaaark (IB_HBW)* *outbound home-based other (OB_HBO)* *inbound home-based other (IB_HBO)* *on home-based (NHB)* • Morning outbound home-based school (MOB_HBS) • Afternoon outbound home-based school (AOB_HBS) • Inbound Home-based School (IB_HBS) • Local distribution (Local_D) • Long distribution (Long_D) • Segmentation by Mode of travel: *Motorised Road (Passenger Vehicle)* *Public Transport (Rail)* *Public Transport (Bus)* *Public Transport (Metro)* • Walking and cycling times included in PT but teleported in the model
Agent's preference methodology	Survey of Residents of Tyne and Wear -Stated Preference Survey Census 2011 A population matrix showing the user demographics of resident users in each zone of the study area. The population matrix will be segmented home zone, user age, user gender and user spending power. Home zone | age | gender | spending power | number of users] "Age" will segment within the matrices in the following groups: • 15-19 • 20-29 • 30-39 • 40-49 • 50-59 • 60-64 • 65+ **"Spending Power"** will segment within the matrices by in the following groups: • Group 1 (contains the 20% of users with the lowest spending power) • Group 2 • Group 3 • Group 4 • Group 5 (contain the 20% of users with the highest spending power) Description of methodology to assign spending power is described in chapter 4

Feature	DeMAND Agent-based model
Software	MATSim PT2MATSim to generate PT network
Demand Data Sources	• Anonymised and Aggregated Data created on weekdays between Monday 5th March 2018 and Friday 29th March 2018 by using the data events collected from 25 million handsets on the O2 mobile network • Trips are allocated to start, and end zones based on a zone system covering the whole UK, comprised of groups of Lower Layer Super Output Area (LSOAs) • A trip-chain dataset showing travel patterns segmented by zone, time of travel and an aggregated number of users • An origin-destination matrix showing the average weekday (Monday to Friday) number of person trips starting, ending or passing through the study area. This matrix will be segmented by start zone, end zone, purpose, time of day, mode of travel • An origin-destination matrix showing the average weekday (Monday to Friday) travel time of users starting, ending or passing through the study area. This matrix will be segmented by start zone, end zone, time of day, mode of travel • An origin-destination matrix showing the average weekday (Monday to Friday) number of person trips starting, ending or passing through the study area. This matrix will be segmented by "trip chain zones" and "trip chain time of day"
Supply Data	• Road Network: Open Street map • General Transit Feed Specification (GTFS) data for bus network • NatRail data extracted from UK2GTFS (https://github.com/ITSLeeds/UK2GTFS) • Activity locations: • Education information from Edubase • Leisure and Retail from the Consumer Data Research Centre Retail Boundary Dataset (https://www.cdrc.ac.uk/) • Work location data derived from Ordnance Survey (Master Map)
Data for calibration and validation PT patronage	Public Transport data from Nexus (the passenger transport executive for Tyne and Wear) covering the two financial years 2017-18 and 2018-19 (received on 9th October): Patronage estimating surveys (continuous monitoring): • 8000 interviews per 4-week period on Metro: scaling carried out over 3 periods • 33,000 interviews per 4-week period on Bus: scaling carried out over 3 or 6 periods • 1,000 interviews per 4-week period on local heavy rail: scaling carried out over 6 periods • 1,000 interviews per 4-week period on Ferry: scaling carried out over 6 periods • POP Card data (both weekdays and weekends provided for the Metro, but only "Tap in"
Data for calibration and validation (MND datasets)	The validation tests for the MND were delivered by Telefonica and are as follows: • A comparison of Mobile Network Data (MND) home-based trip origins and census zone home population. • A comparison of MND work-based trip destinations and census zone work population. • A comparison of inbound and outbound trips per zone to show symmetry. • A comparison of the MND trip length distribution for all trips compared with the NTS. • A comparison of the MND trip length distribution of commutes compared with census journey to work data. • Trip rates based on expansion targets and zonal trip-ends derived

4.1.1 Zoning System

The model covers the whole of Great Britain with focus on the Tyne and Wear area, therefore, the area has been divided into four levels of zoning system with detailed zoning in Tyne and Wear to capture more refined travel demand. Then further away from Tyne and Wear the spatial granularity of the zoning system gradually decreases.

Groups of Lower Layer Super Output Area (LSOAs), MSOA (Middle Super Output Area), and Local Authority districts are used to define the zoning system.

The zoning system comprises of 998 zones in total:

- Tyne and Wear with 534 zones at LSOA level;
- North East with 464 zones at MSOA level;
- The rest of England with 322 Local Authority District;
- Wales and Scotland as one zone.

4.1.2 Transport Infrastructure, Land Use and Fleet

The road Network for the North East was imported from Open Street Map and is made of 640,000 nodes and over 1,200,000 links. This includes both strategic and local roads.

The Public Transport (PT) network for the North East includes all bus services (844 in Tyne & Wear and 250 outside). The rail network stretches nationally and includes the 230 rails services connecting the North East with the rest of the UK.

Cycling lanes and segregated walking/cycling path are also included in the transport infrastructure.

The multimodal PT network was built using publicly available datasets: bus timetables from the TraveLine database; rail timetables services from Association of Train Operating Companies (now RSSB); bus stops and train stations are loaded from the National Public Transport Access Nodes (NaPTAN) database from Department for Transport (UK); average fares structure generated using fares from PT operators.

Each zone in the North East is made of residential areas, which are point of origins and points of destinations for the agents. The location of these facilities is known and is available in open access datasets available in the Consumer Data Centre, Edubase and the Royal Mail Address base dataset and Ordnance Survey Master Map. Activity locations comprises Home, Work, Leisure, Education and business parks.

Fleet composition comprises detailed information on capacity and vehicle measurements for Light and Heavy Goods Vehicles were collected from the Driver and Vehicle Licensing Agency (DVLA).

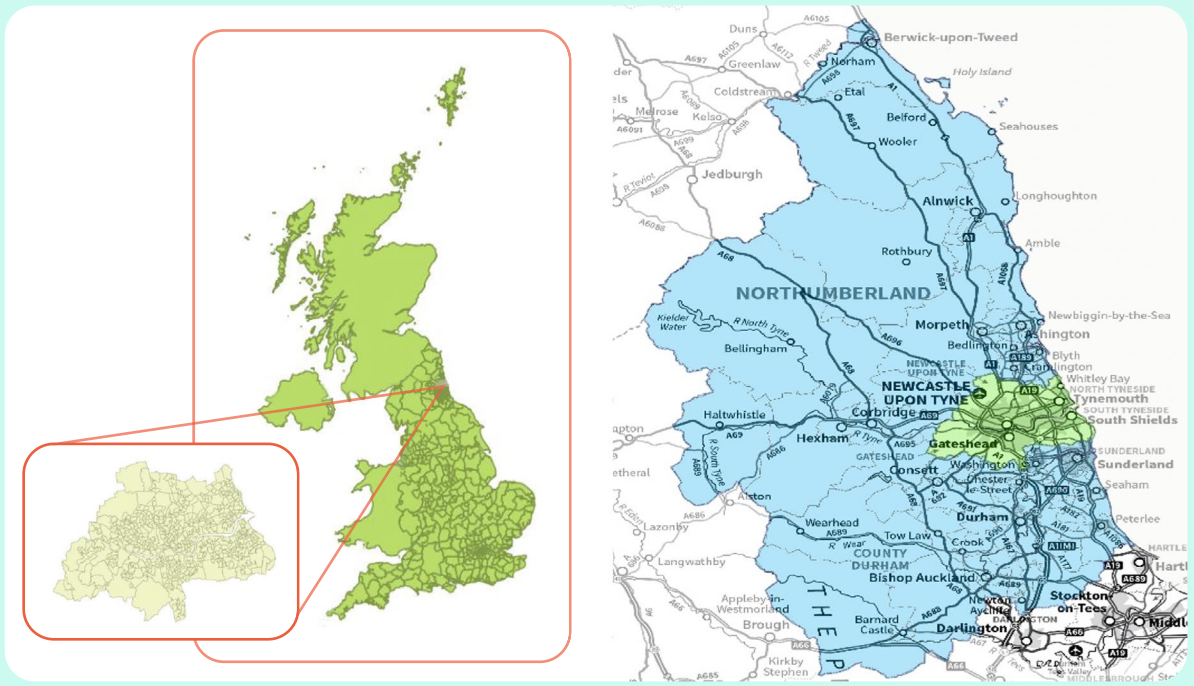
Tyne and Wear

Case Study Intro

Location of the prototype is Tyne and Wear in the North East of England. With the lowest rate of car ownership in UK, Tyne and Wear users are already relying on an efficient Public Transport system, where the underground (Metro) is operating alongside a balanced presence of major bus operators in the metropolitan area.

A scenario was designed to introduce a DRT in newly Id areas and in areas where public transport has a comparatively lower level of service, creating transport poverty conditions (in case the user has no access to a car) or an increased dependency on the availability of private cars. However, project constraints only allowed for preliminary analysis.

Figure 10: Location of the demonstrator



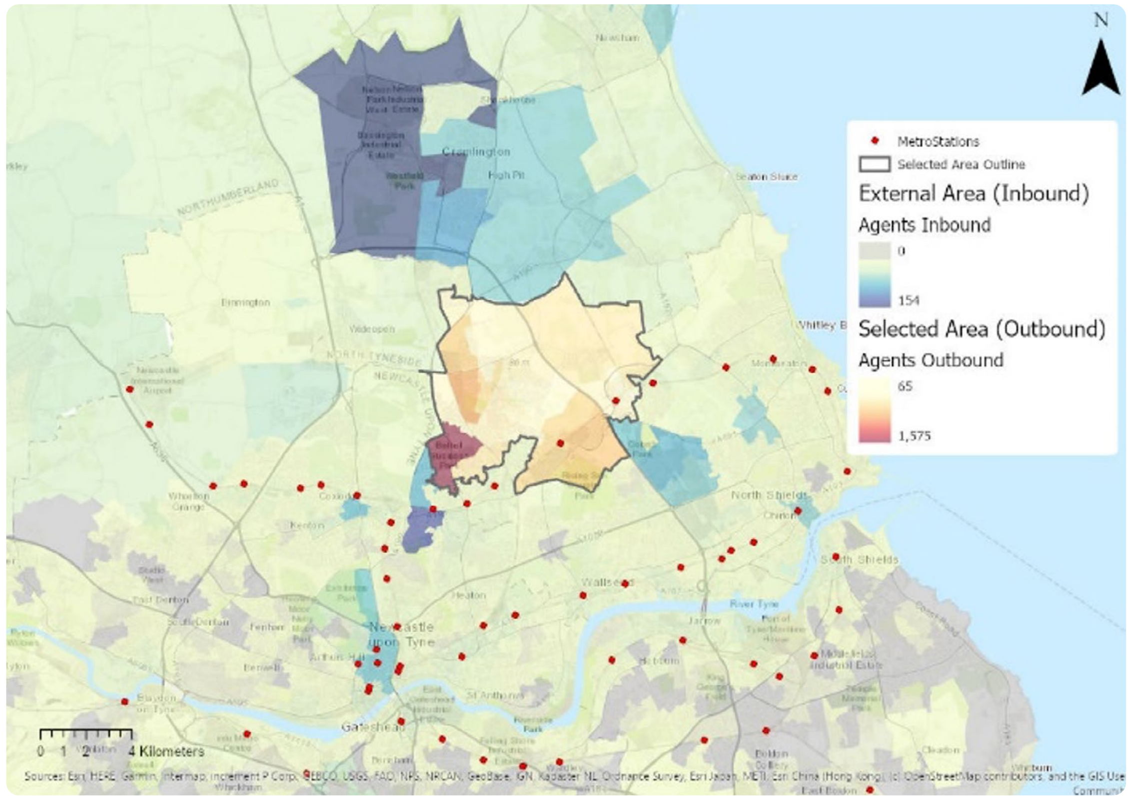
Insights from this study will add value for Nexus, the Passenger Transport Executive for Tyne and Wear, and the North East Combined Authority (now Transport North East) to support their initiatives on the introduction of New Mobility services, target early adopters and adjust the level of service to their preference. Moreover, DfT and other stakeholders can increase the knowledge base around public opinion of shared mobility services and the factors that influence opinion of these services, as well as the development of ABM for this purpose.

4.2 Model results

The DeMAND MATSim model represents a digital twin of Tyne and Wear and the North East of England for an average day in 2018. The synthetic population built using activities derived from Mobile Network data allows to see the door-to door travel patterns from residents (simple and complex tours where starting zone and end zone are the same), and also, all the outbound and inbound journeys from people not living within the study area, that are normally difficult to capture with traditional survey methods.

During the project some preliminary analysis identified an area comprised between the Cramlington trainline to the west and the Metro line to the South and East and the B1321 to the North as a possible area where an introduction of DRT may yield benefit.

Figure 11: MATSim agent simulation of the target area for DRT implementation



This area is rich in public transport services, comprising residential areas (Forest Hall, West Moor, Killingworth Village and Holystone Village) and industrial parks, but still strongly reliant on private cars. However, agents commuting in this area are coming mainly from Northumberland rather than the local area. Therefore, a DRT service could make the use of public transport more attractive by linking the commuters with the closest bus and metro stops serving the industrial parks.

4.2.1 Model Calibration and results analysis

Validation and calibration of a model involve subsequent adjustments of the model to ensure observed behaviour and characteristics are represented in a realistic and accurate manner.

In the traditional transport assignment models, the following validation and calibration exercises are expected:

- **Network:** checks for errors and validate against observed data, e.g. flows, speeds, journey time
- **Route choice:** checks on the plausibility of modelled routes
- **Demand matrices:** checks on origin-destination movements and validate against observed flows
- **Assignment:** stress testing the model results and validate

Agent based modelling for the transport sector is relatively new in the UK, therefore, standard processes of model validation and calibration have not been established.

Ideally, the validation and calibration of DeMAND may be carried out similarly to the traditional models and may have to be extended following the nature of ABM:

- Tasks and activities that are conducted prior to the commencement of any modelling, including network checking and verification of geometry, number of lanes;
- Initial validation of model parameter values on the basis of available field data, including link characteristics such as macroscopic speed-flow-density relationships; driver behaviour characteristics such as routing strategies and gap acceptance requirements; and origin-destination traffic demands;
- Results from the model are compared to field conditions.

Due to limited timescales for this project, a robust model calibration and validation did not take place. However, network checking and verification of the geometry were carried out, followed by initial calibration, using available data, particularly routing strategies and scoring parameters derived from the mode choice modelling and results.

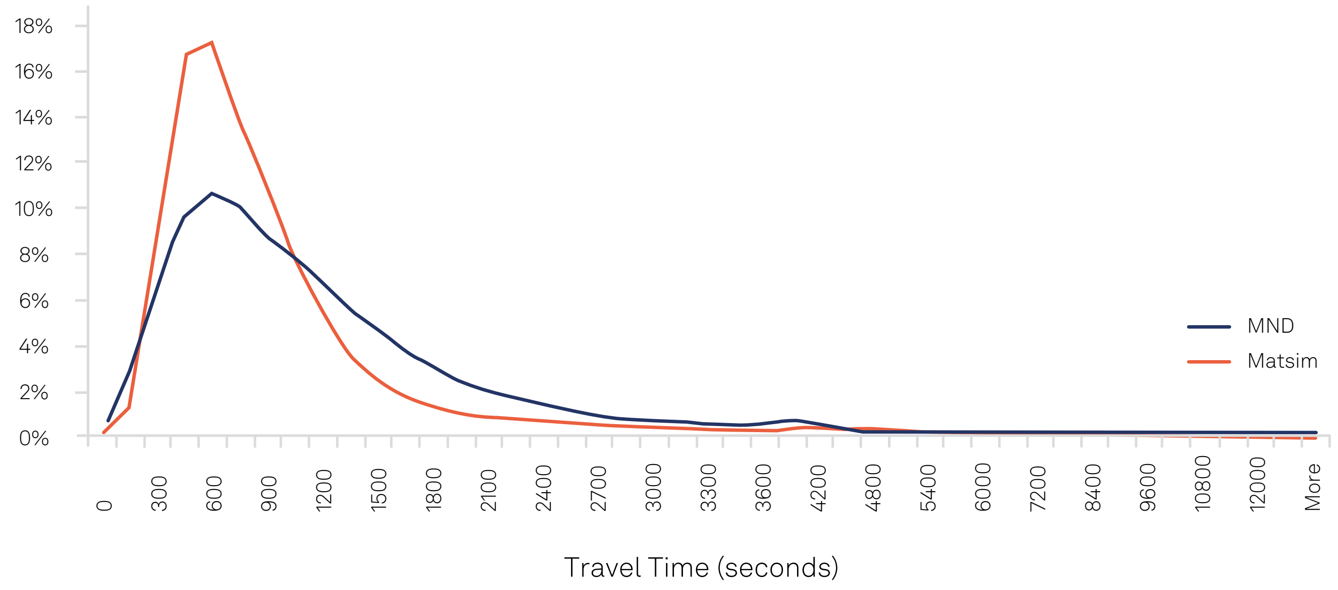
The current setup of the model does not contain information on the traffic light settings, and junctions have been considered un-signalised. This has an expected impact on the overall and individual ODs travel times, and could be part of a future exercise since it requires a huge effort and information that were not available during the project.

4.2.2 Verification and comparison of results

Regression analysis was performed comparing the travel times measured from MND and those modelled (MATSim) for the same OD pair.

The MND travel time dataset is derived from several trips which are averaged and reported in the MND OD travel time matrix. Similarly, to the process behind the MND OD pair travel time calculation, only certain OD pairs with a certain number of agents travelling during the simulation period were considered. In this way the travel time will be based on a statistically significant average value.

Figure 12: Comparative Regression analysis of frequency distribution of agents' travel time



A sensitivity analysis of the regression plots was performed by considering different minimum number of agents traveling on a certain OD pair, upon which we would perform the calculation of the average travel time. Hence, for the sensitivity analysis, six different groups of ODs were considered: those with a minimum of 5, 10, 15, 20, 25 and 30 agents respectively have been analysed. Comparison for the ODs with five or more agents has an R2 of 0.83, which is already good, however the slope (0.53) and intercept (186 seconds) shows an overall speed of the agents higher than the one observed. This is persistent in all graphs indicating, as expected, that the absence of signalised junction and extra delay in certain intersection may have played an important role. However, at the same time, the result provides confidence that the overall behaviour of the model and the agents is very consistent across the entire network, which is what the prototype wants to demonstrate.

5 Conclusions

The “Demand Modelling and Assessment through a Network Demonstrator” (DeMAND) project focuses on the development of a new methodology to assess the demand for the introduction of New Mobility Services (NMS) in urban areas.

Multimodality and attitudes towards sharing will affect how people travel in the future and demand modelling must move away from the traditional division of transport modes. Travel behaviour is gradually getting more difficult to predict, hence the increased complexity of modern travel needs transport models that fits modern lifestyle, and accounts for the introduction of autonomous and flexible mobility services. Moreover, an ageing population will require new ways to travel and to be more independent for longer.

5.1 Findings

The DeMAND project developed a prototype to provide decision makers with a tool to appraise Mobility as a Service (MaaS) schemes and emerging on-demand mobility services.
The tool follows the following approach:

- End-to-end users' journeys;
- Multimodality, where private on-demand services are integrated to the public transport ecosystem;
- The variability over 24 hours of travel patterns to identify demand at different times of the day and for a large-scale area in order to capture all mobility needs (even beyond the administrative boundaries of a council).

The prototype was built using the open-source platform MATSim, a multi-agent micro-simulation model, where each modelled agent (in this case residents) contains its individual settings. The demand modelled is optimised individually for each agent, as a complete temporal dynamic description of the daily demand.

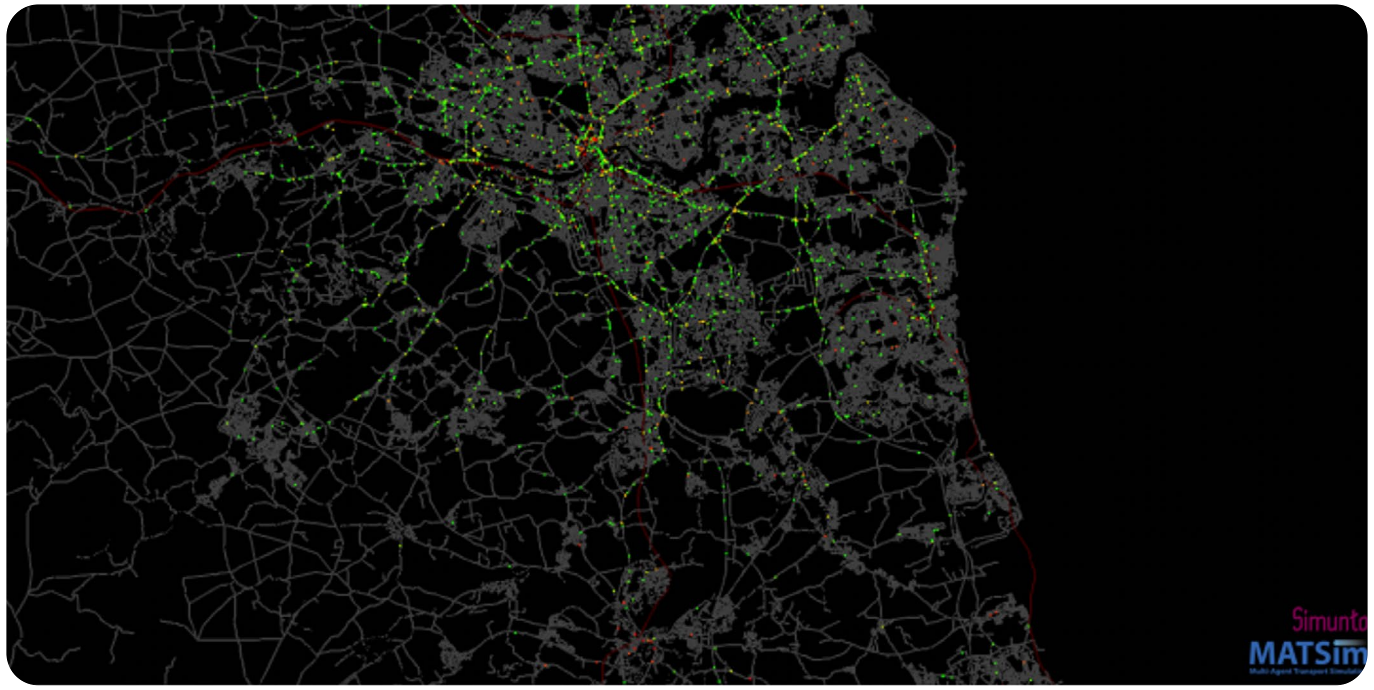


Figure 13: Visualisation of the DeMAND MATSim model using Via

Digital twin for the Tyne and Wear

The DeMAND MATSim model represents a digital twin of Tyne and Wear and the North East of England for an average day in 2018. The synthetic population built using activity-chains from Mobile Network data shows the door-to door travel patterns from residents (simple and complex tours where starting zone and end zone are the same), and also, all the outbound and inbound journeys from people not living within the study area, that are normally difficult to capture with traditional survey methods.

Understanding of how people movements and their transport choices and preference enables decision makers to test a variety of mobility services, either in integration with current public transport or not. Identifying demand and catchment area for the service is a straightforward application for the model, which enables planning for integrated services with bus, rail or aviation and targeting the possible early adopters depending on the characteristics of the service.

Generation of a synthetic population using Mobile Network Data

The DEMAND model represents a synthetic population of nearly 650,000 agents (individual people) replicating the transport choices and preferences within Tyne and Wear (population 1.136 million in 2018) in the North East of England. Each agent bears the socio-demographics characteristics, spatial information, and daily activity schedules from the use of anonymised and aggregated mobile network data (MND) sourced from O2Motion (Telefonica).

The metropolitan area was chosen as a case study for its greater propensity for using public transport and to identify ways to improve current level of service with the introduction of 'on-demand' shared modes (restricted to demand responsive transport for this study) when running in integration with a multimodal public transport system.

The methodology developed during the DeMAND uses a data exploratory framework to accelerate the generation of the travel plans for the synthetic population. Despite the model is focused on Tyne and Wear and the North East, travel patterns span across the UK, scaling it at national level.

The model includes the road network for the North East (including minor roads), and a multimodal public transport network with 844 bus services (of which 250 in rural areas), 230 rail services connecting the North East with the rest of the UK.

Uptake of shared mobility

Results from the survey of residents and stated preferred survey carried out enable behavioural models to be set up that includes transport choices and agents' preferences in the model.

Survey results highlighted:

- Respondents were hesitant about sharing a journey with strangers: concerns on perceived comfort (68%), privacy (67%) and safety (62%)

- The majority of people (66%) are unlikely to consider a shared transport mode, with 17% of respondents likely to consider it. Younger residents aged under 40 (26%) and those with household incomes of over £60K (25%) are most likely to consider shared transport (but only for leisure and shopping purpose). This implies different social rules compared to sharing a busy tube carriage or bus. Early adopters of the shared service are car drivers:
  - 35% are 'Older less mobile car owners' (defined as mature adults with mobility difficulties that travel less compared to other car owners)
  - 24% are 'Town and rural heavy car use' (defined as working age, higher income, but less educate in rural/urban areas with high level of car ownership and car travel, 13% of UK population)
- Knowing the route increased the perception of control and safety among potential passengers
- Users in Tyne and Wear will be keen to walk around 10 minutes to reach the pickup point if this helps in streamlining the service and reduce times in diversion because of other passengers on board. This solution can lead to a more appealing shared transport service, but also encourage people to be active

Evidence from the survey has been used to tailor transport choices and preferences in the model, estimating the coefficients for the MATSim scoring of the daily travel plans. Each travel plan carried out by an agent is scored against marginal utilities linked to the activity and the mode of travel used.

Two nested logit models were developed for two groups of purposes (i.e. work/study and leisure/shopping) for incomes below £60k and above £60k. The coefficients used for these models, including the value of times for shared modes, can be transferred to other modelling applications in the future.

Active Travel

One of the biggest limitations in using mobile network data to generate the population for the DeMAND model is the inability to capture short journeys (2-5 miles). It was found from the survey that just over half of car journeys were of five miles or less with the mean journey distance approximately nine miles.

Some car journeys have the potential to switch to ride sharing or active travel (walking and cycling), especially when on segregated pathways. The stated preference survey also revealed a propensity to consider the value of time linked to active travel similar to the one linked to shared mobility. Hence, further investigation should be carried out to find out the propensity towards active modes.

Local and long distribution of goods

In the model, freight movement (5% of total agents) can be identified using trip-chains information from mobile network data. The higher temporal granularity used in DeMAND allows the identification of patterns, working practice in both local and long distribution, without the need to collect data from logistics operator.

Initial calibration and results comparison

The DeMAND agent-based model has demonstrated the ability to model a large-scale area, using only readily available network information (Open Street map, census and demographics) and latest generation of Mobile Network Data, including both origin and destination matrices and trip-chain information across the identified area. However, being a prototype means that there is still potential to develop the model and associated techniques further to deliver significant improvements over what has been produced to date.

5.2 The DeMAND prototype is a proof of concept, that includes highway and public transport assignment in the same platform. The integration of new data sources and traditional estimates for travel behaviours have been rewarding, but the constraints of a time limited project did not allow all areas to be fully developed. Looking to the future, further projects using this modelling platform and methodology could examine the following areas:

- Sensitivity analysis to adjust the innovation strategy in the model and the substitution of the MATSim scoring function for shared mobility;
- Scenario testing for new mobility services (including integration with aviation and rail modes);
- Developing suitable validation and calibration techniques and criteria. This will likely require additional datasets and further investigation to adapt technique used in traditional transport modelling as outlined in DfT’s TAG Unit M2.1 for demand modelling. Also, access to real-world traffic and Public Transport (PT) flows will enable further validation of the model against criteria similar to the ones outlined in DfT’s TAG M3.1 (highway assignment) and TAG M3.2 (PT assignment).

Sensitivity analysis and scoring function for shared mobility services

The DeMAND model has the potential to assess shared mobility services but the current MATSim scoring function needs to be substituted to allow the consideration of changing the value of time according to activity type and agents’ characteristics. This requires a considerable computational effort considering the complexity of the new scoring function developed.

The base year model 2018 was set up using the standard scoring function in MATSim with coefficient obtained from the Stated Preference Survey (SPS). The code generated to implement the new scoring function was developed alongside new coefficients derived from the stated preference survey. Next step will be the implementation of the new scoring where a higher value of time is applied to activities which are time constrained.

Also, a sensitivity analysis needs to be carried out to identify the best performing strategy settings.

Integration with Rail and Aviation services

The same technique could be applied to integrate the service to rail or aviation, exploring different types of segments of population. New Mobility Services can be delivered using autonomous vehicles or drones for moving people and goods. In that case, cost and scoring functions should be updated to reflect users’ acceptance of these technologies.

Some scenarios that we were planning to explore with interested stakeholders are:

- Future of Mobility in Tyne and Wear involving participation of North East Combined Authority and Local Authorities in Tyne and Wear;
- Introduction of Mobility services in integration with Rail services analysing the travel habits from rail users and real catchment area of the train stations, looking at the end-to-end users’ journeys using Mobile Network Data at activity level;
- New mobility service in integration with the aviation sector;
- Changing travel habits during Covid-19 lockdown to provide new strategies for the “new normal”;
- Forecasting demand introducing new techniques to predict agents’ preferences (e.g. virtual reality applications) and population forecast techniques.

Calibration and Validation

The model, being a ‘Proof of Concept’, cannot be considered a mature product, if compared with standard and traditional transport model, however this project has shown the capability of the MATSim model to represent trip-chain and agents at a finer resolution, as well as its ability and flexibility in representing large scale networks with limited data.

The DeMAND model was never meant to be fully compliant with the DfT’s TAG. Further work will be required to expand guidance to include agent-based and activity-based modelling and reflect the need for bigger dataset for calibration and validation rather than using local (and manual) and limited data. Also, tests for convergence, realism and sensitivity should be extended to cover data-driven agent-based models.

Next steps could also be dedicated at extending the DeMAND prototype by refining the network (e.g. the setting of traffic lights and key junctions delay) to provide a significant boost in the model performance and carry out a full calibration, followed by a validation of the model.

It is envisaged that in addition to the journey time, other validation parameters and datasets will be used, namely counts on links, speeds/journey time from ANPR cameras, useful for MND travel time validation, etc.

Tyne and Wear has a repository of traffic data available at Traffic and Accident Data Unit (TADU) but also the UTMC Centre and Urban Observatory hosted by Newcastle University, that can be the sources of the majority of those additional validation datasets. Some testing of the model through sensitivity analysis of different parameters will provide evidence of the robustness of the model but also allow a more realistic simulation and to assess model performance under different scenarios.

5.3 Further work

The development of agent-based models with a higher granularity of information can support planning and operation for Passenger Transport Authorities. We should seek coordinated and integrated transport solution with local and national passenger authorities to support future of mobility strategies.

The DeMAND methodology is valid in a data-rich environment. However, there is no guarantee that the same methodology can be applied in rural areas where limited data are present and often outdated and not reflecting current travel needs. Hence the need to explore how alternative data source, such as mobile network data could perform in a rural context.

5.3.1 Assessing Sustainable Transport Solutions (AsSeTS) for Rural Mobility

A sSeTS for Rural mobility project aimed at improving the knowledge base around demand for new mobility services in rural area by exploring alternative data sources.

Predicting the demand for new mobility services (NMS) in rural areas is critical to the design and operation of the commercially viable services. Although traditional datasets are available in rural areas, these don't reflect current mobility needs and can be too aggregated to be able to inform mobility services providers. The use of new data sources, such as anonymised Mobile Network Data (MND) aggregated at trip-chain level can be used to reveal real travel patterns in rural areas. This study aimed at establishing if a data-driven methodology has merit and can provide the level of fidelity and confidence required by industry to launch on-demand mobility services.

The AsSeTS for Rural Mobility project identified ways to improve accessibility and transport solutions in rural environments by improving the knowledge base around demand for new mobility services. This was achieved by exploring alternative data sources and exploring tailored interventions to rural areas.

In doing so, the project identifies and suggests ways to remove barriers which prevent NMS being commercially viable in rural areas by:

- xploring alternative data sources to represent demand for travel in a rural context

- Exploring tailored interventions, estimating the effectiveness of different NMS solutions for meeting expectations for rural transport demand

The project also demonstrated that rural areas (traditionally carbon intensive communities) are driving the increase in last mile deliveries, with local logistics accounting for 95% of road freight regionally.

Since the growth in carbon intensive last mile road freight deliveries in rural areas risks compromising the Government ambitions for 'net-zero' greenhouse gas emissions, a new study is under development to assess the use of agent-based models for assessing last mile deliveries interventions.

5.3.2 Rural Innovation for Sustainable Environments (RISE) for Decarbonising Last Mile Road Freight

Within the DfT's Future of Rural Mobility Strategy, this project aims to demonstrate that demand agent-based models integrated with emissions modelling can explore alternative decarbonising pathways for last-mile rural deliveries. The agent-based model explores the link between consumers' behaviour and freight deliveries and, in integration with emission modelling, determine last-mile freight emissions' impacts. This holistic analysis will reveal the freight demand connection between urban and rural areas.

In order to support change to new sustainable mobility services for goods, it is necessary to develop viable business, environmental and social cases for new logistic practices. To date this has been hampered by the lack of top-level relevant data for road freight. RISE will adopt an agent-based approach to complement traditional models with main aims to:

- Understand the role of consolidation centres and last mile deliveries considering the close bond between rural and urban areas
- Holistically test the efficiency gains from new mobility services for goods, multimodality, changing travel behaviours from consumers and logistics operators through more efficient transport chains and last mile services
- Develop insights from data that can be exploited at a national scale, and explore barriers to greater collaboration
- Develop guidance to support DfT in creating policy proposals based on these findings to ensure emissions reductions from rural last mile deliveries can be achieved
- Explore sectoral attitudes about modal shift from road to rail, the deployment of clean logistics vehicles

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