ROLE OF INTELLIGENT TRANSPORT SYSTEMS (ITS) APPLICATIONS IN THE UPTAKE OF MOBILITY ON DEMAND SERVICES

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ABSTRACT

Flexible demand mobility services and shared mobility are presented as the way forward to achieve Mobility as a Service. Nowadays, an Intelligent Transport Systems application in users' devices is as little as it takes for an operator to launch a service. However, mobility services companies operate in a way that is disruptive and often not sustainable at scale, entering in direct competition with mass transit. They follow a process of trial and error in the attempt to attract demand. This paper focuses on the introduction of a seamless, integrated and easy to use demand responsive transit, thanks to the use of a mobile applications which allows access to the service in integration with existing bus services. The evaluation of the ITS flexible service is carried out using an Agent Based Model, which uses disaggregated data, including those coming from the mobile application, to deliver a comprehensive understanding of travel patterns. The tool is ideal for regeneration and expansion areas where very little data is available which is of great interest for many Asia-Pacific growing cities. Demand is identified using anonymized and aggregated Mobile Phone Network Data (MND), which inform the end-to-end user journeys in the model. Results from the Innovate UK funded project "Mobility on Demand Laboratory Environment" demonstrate that a data-driven approach is able to identify demand for mobility services ahead of the launch. The platform is designed to facilitate real-world deployment in integration with existing mass transit. Also, local authorities can benefit from the data-driven approach, which can be transferred to other geographies where transport data is insufficient to assess the introduction of new mobility services.

Keywords: mobile application, demand-responsive transit, agent-based modelling, Mobile Phone Network Data, multimodal public transport, end-to-end user journeys

I. INTRODUCTION

Flexible demand mobility services and shared mobility are presented as the way forward to achieve Mobility as a Service (MaaS). However, the introduction of ride sharing mobility services in urban areas is challenging the balance between private and public transport. The use of mobile applications has enabled private operators to easily reach the customers, collect data and learn from the usage of the service. Most of the time the operator works in isolation, which is disruptive and not sustainable at scale. Mobility services operators don't follow a specific strategy prior to activating a service but undergo a process of trial and error in the attempt to attract demand, however, they could provide a useful asset for the public transport sector, extending the catchment area of services and acting as feeder for the fixed scheduled public transport.

With the introduction of MaaS it is even easier to integrate seamlessly the tickets and allow the user to have a multimodal door to door service without the need to use their own private car. Data collected from the use of the service can improve the service itself in the operation but not during the planning phase ahead of the launch. Many data currently collected for other purposes and data from local authorities could help in planning a flexible mobility service which works in cooperation with fixed scheduled public transport services.

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However, many strategic modelling tools are designed to determine traffic flows from private cars and public transport but are not fit for the purpose to represent the functionality of a demand responsive transit. Moreover, they're mainly trip based, which makes difficult to understand the end-to-end users journey and identify potential customers for mobility services providers. Using these tools, it is impossible to predict how a Demand Responsive Transit (DRT) can contribute to improve the level of service to the users or quantify first mile and last mile service. Currently operators collect data from their services, hence at micro scale but don't focus on a strategic planning at city level or even beyond.

This paper focuses on how to use these datasets to inform an agent-based model (ABM) to represent city wide commuting patterns, identify demand and handle disaggregated data, such as MND, public transport data, telematics and data feeds on usage of the DRT. Moreover, this platform is built on an open tool and the process used to build the synthetics population can be transferred to many other geographies which do not have historical data (i.e. expansion areas, regeneration areas).

The following sections of the paper report on a literature on DRT and MaaS applications in the Asia-Pacific area, how the planning of the operation is considered and if there was any direct learning for policy makers. The section that follows sets out the design of the ABM model developed for the case study of Greater Bristol in UK, followed by a summary of the simulations and results achieved. The paper concludes with the implications, the results achieved in the operations of the DRT services introduced and some considerations on limitations and how to improve further the model.

II. Literature review on Demand Responsive Transit (DRT)

The DRT or mobility on demand services are now used in urban areas to cover first mile and last mile leg in longer journeys. With the introduction of Intelligent Transport Systems and smart technologies the accessibility of these services to users have been increasingly seamless and integrated with other public transport services. However, the DRT was associated in the past with low demand areas which required an ad hoc service in order to provide social inclusion in rural areas (Mulley et al., 2009). Also, Wang et al. (2018) found out that DRT covers the needs of disabled, users travelling for work, or live in less densely populated areas.

However, Davison et al. (2014) in a review highlighted that when a DRT service is launched in developing countries it is going to be mainly market and profit driven; while when launched in developed countries such opportunities have been restricted to niche markets or priority has been given to social inclusion or in supporting specific type of users. This found confirmation in the recent interest of the automotive industry in the Asia to apply disruptive innovations linked to new approaches to mobility. Future Centre Asia, for example, was funded by the Volkswagen Group to understand how Chinese and Asian market are welcoming these changes in mobility and how insights from data automatically collected can replace local knowledge[3].

There is a focus in adapting the future mobility services to the needs of customers who tend to be younger, digitally connected and with an open mind to new solutions. Other automotive groups are concentrated instead in providing services attached to shopping and leisure facilities, creating alliance with shopping malls. Customers in Tokyo and in Hong Kong can benefit from a premium service, Audi on demand[4]. And they plan to scale up to China. They tailor the service on local factors and customer requirements in a specific market to customize the service according to the locations where it is running (i.e. a luxury residential complex) and the limitations of this location (i.e. lack of parking or parking restrictions).

Flexible transport can take many different forms. In the FLIPPER Project,[5] Flexible Transport Services and ICT platform for Eco-Mobility in urban and rural European areas, (Enoch et al, 2004) a detailed description of 70 schemes around the world is available. DRT is considered a hybrid transport service options offering user-generated routes but for a higher fare than fixed scheduled mass transit.

[3] https://www.volkswagenag.com/en/news/2018/01/Future_Center_Asia.html (accessed 22/10/2018)

[4] https://www.audi-mediacenter.com/en/press-releases/audi-expands-mobility-network-in-asia-10311

[5] http://www.interreg4cflipper.eu (accessed 22/10/2018)

Frei et al. (2017) shown that mobility service operators, such as Uber and Lyft, offer a competing form of taxi service for many travellers; while preliminary research has shown they may complement transit service in underserved areas, however long-term impacts are not yet clear (Shared Use Mobility Center, 2016). Other mobile applications for hailing taxicabs are also available, and the regulatory definitions and policies to distinguish traditional ride-sharing, taxi/livery services, and public transport are evolving (Yousef, 2014).

Evidence (Daniels et al., 2010) shows that flexible transport services are not used as widely in Asia-Pacific as they are in other countries including the UK and Europe, despite their potential to increase accessibility and improve social inclusion where conventional public transport services are not viable. Barriers were grouped into five themes: (i) policy, legislation and regulatory environment; (ii) economic issues of funding, costs and fares; (iii) operational issues of fleet and vehicles; (iv) attitudes, culture and perceptions amongst stakeholders; and (v) barriers of information and education about flexible transport services. Mulley et al. (2012) have concluded that in the Australian region it is the very flexibility of DRT - in terms of service structuring, service organization, and service delivery options - that represents their greatest asset in meeting the cost-effectiveness challenge.

Improving public transport has long been argued as an alternative to car use in many western countries and substantial funds spent on improving both quantity and quality of bus and rail services (Banister, 2008; Chapman, 2007; and Sharaby et al., 2012). Attitude about the quality of public transport services is a key issue on the perception of users' satisfaction and actual use (Friman et al., 2009; and Shiftan et al., 2008). However, in developing countries, most trips are already conducted by public transport, but many services are informal and unregulated and often compete sometimes aggressively against the better organized and safer formal public transport modes (Cervero et al., 2007). These informal modes, in some cases falling within the remit of DRT, often clog city centres generating congestion as well as severe environmental problems and safety hazards. This is a challenge for the future of urban mobility that needs to be carefully addressed by decision makers.

Effective road-based public transport is central to economic growth of developing cities. For the majority of residents in developing countries, road-based public transport (bus and paratransit) is the only mean to access employment, education, and public services. In medium and large developing cities, such destinations are beyond viable walking and cycling distances while vast numbers of individuals have limited access to cars (Pojani et al., 2016). Unfortunately, the current state of road-based public transport services in many developing cities does not serve the mobility needs of the population adequately. Formal bus services are often unreliable, inconvenient, uncomfortable, or even dangerous. Informal paratransit services, while providing benefits including on-demand mobility for the transit-dependent, jobs for low-skilled workers, and service coverage in areas devoid of formal transit supply, carry major costs, such as increased traffic congestion, air and noise pollution and traffic accidents (Cervero et al., 2007).

The Role of Technology

What makes the difference in today's services is the use of telematics-based Flexible Demand Services which have the scope to bring public transport closer to the flexibility and convenience of private transport, whilst retaining a fare structure more in line with public transport journeys, as opposed to the most flexible – but costly – private hire and taxis (Mulley et al., 2009).

At a simplistic level we know there are many buses and other vehicles out there that remain underutilized. People want to get from A to B but are unsure where these buses are parked and believe they only operate on fixed routes. The solution that connects these elements together is technology. If people have a flexible way of knowing or demanding this travel, then DRT can provide the solution. DRT can make a significant contribution to the creation of better, more integrated local passenger transport networks that can meet more needs, being the first and best choice for making a journey (CTA, 2017).

The role of technology in the public transport sector should be also taken into account for future plan. For example, in the Malaysia National Land Public Transport Master Plan (Land Public Transport Commission, 2014) there is an ambitious objective to achieve a land public transport modal share of 40 per cent in urban areas, as well as enhance access in underserved rural areas, while increasing connectivity between locations. Actions are on the right direction, however with a digital population fast growing, achieving the NLPTMP objectives without considering a centralized policy embedding DRT and its flexible approach may result in difficulty to achieve the goal.

Modelling Applications

A previous study demonstrated that a minibus service can offer a greater accessibility in residential areas, thus increasing bus patronage (Ambrosino et al., 2016). However, costs for the bus companies are too high to be sustainable. As pointed out by Navidi et al. (2018), fixed scheduled public transport is no longer functional to satisfy the demand for travel. Real time information and computational power make it possible to use new generation tools. His results demonstrated replacing conventional public transport with demand responsive transport will improve the mobility by decreasing the perceived travel time by passengers without any extra cost.

Other studies explored how the introduction of MaaS is eliminating the traditional division between collective transport and individual private transport[6]. In recent years, public transport services have been complemented either by DRT services, which serve a dispersed demand or by Flexible Transport Services (FTS), which focus on a complete satisfaction of user needs and can be on a not shared or shared basis. Whilst business models have been explored in many EU Countries (Bell et al., 2012; and Franco et al., 2012) operations are not standardized yet and different approaches are adopted.

To test and explore the efficiency of flexible and shared service, modelling can help and support in identifying those areas that are currently served by inaccessible, unaffordable and inappropriate public transport (Auld et al., 2016). Previous studies tried to tackle the agent-based approach, integrating an ABM, built with UrbanSim platform with a four-stage transport model (Hafezi et al., 2017), highlighting that the proposed approach could support the long-term planning impact. However, the activities generated using the trips from the 4-stage model were used to support a strategic model and evaluate the impact of population growth in urban areas.

Recently, with the increased use of big data source and computational power, ABMs have evolved and now include also microscale modelling tools that can provide an ideal environment to assess flexible shared services. Historically, agent-based models were macroscopic models that provided great level of detail and insights in the demand modelling, especially in representing trip chain. Recent advancement in the ABM sector allows not only use of traditional demographics and land use data, but also inclusion of new disaggregated data source (Ho et al., 2018). The agent-based model represents a wide area at a microscale level, which was not possible to achieve in the past and it is still not possible with traditional traffic microsimulation software (Balmer et al., 2004).

Synthetic population in ABM was built using census data (Balmer, 2004) and an activity-based models were used to generate travel patterns with socio demographics characteristics often coming from large household travel diary surveys. Auld (Alexander et al., 2015) developed a new comprehensive pattern recognition modelling framework that leveraged activity data to derive clusters of homogeneous daily activity patterns (Meister et al., 2010). Based on the socio-demographic characteristics of individuals they identified which cluster individuals belonged to, and predicted various information related to their activities, such as start time, duration, travel distance, and travel mode, for use in agent-based travel demand modelling.

In the last decades, the shift from using typically aggregated data to more detailed, individual based, complex data (e.g. GPS tracking) and the continuously growing computer performance on fixed price level lead to the possibility of using microscopic models for large scale planning regions (Wang et al., 2018). An open software platform, MatSim, developed by the Technische Universität of Berlin and the Swiss Federal Institute of Technology in Zurich (ETH Zurich) has been used to explore changes in the transport systems and the uptake of new technologies. MatSim is a multi-agent micro-simulation model. In MATSim each modelled agent (person, vehicle, etc) contains its individual settings, made of demographic information and the daily plan. The sum of all physical agents reflects the statistically representative demographics of the region. The demand is modelled and optimized individually for each

[6] Locked Out: Transport Poverty in England, SUSTRANS https://www.sustrans.org.uk/lockedout

agent, not only for some parts of the demand like departure time and route choice, but as a complete temporal dynamic description of the daily demand of each agent.

The Future Cities Laboratory is a transdisciplinary research centre focused on urban sustainability, located in Singapore, established by ETH Zurich and the Singapore's National Research Foundation. A MATSim complete model for Singapore was built to identify initial demand modelling based on diverse sources of data, such as the Household Interview, Travel Surveys shared by Land Transport Authority (LTA), land use information from Urban Redevelopment Authority, NAVTEQ (base electronic navigable maps) and diverse web resources. The simulation covers both public and private transport and their interactions. However, they claim that no immediate relevance to policy and planning has been identified (Banister, 2008).

Finally, a Last-mile Evacuation simulation was developed for the Indonesian City of Padang, which faces a high risk of being hit by a tsunami. A realistic simulation of the evacuation process helps to give an estimate of the evacuation time, to detect bottlenecks in advance and to identify highly endangered areas, where a vertical evacuation seems the only way.

Research gaps addressed

A main issue highlighted above, especially in the Asia-Pacific regions, is the high probability of disruptive consequences for the Public Transport market by introducing new unregulated private Demand Responsive Transit (DRT) services which can decrease the quality of living in highly densely populated areas.

Many authors have used the ABM approach to visualize demand from users, but the application on DRT and new mobility services is limited. The integration with fixed scheduled public transport will relieve congestion and improve air quality in the urban areas. The ABM, in particular, has the ability to replicate and weight user requirements understanding their travel pattern.

Another major gap noted in the literature is the lack in standardization in the model used but also in the type of data used to build a synthetic population. The choice of utilising MND is quite unique and allows for a rapid collection of data, which reflect the actual status quo and is not dependent by small samples which can potentially be biased. MND are continuously collected and, even if are anonymized and aggregated, can still reveal important insights in the end-to-end user journey. Many previous works on DRT are still based on Census information but also are linked to legacy format of transport models where all demand data is associated to origin destination matrices which are trips-based.

III. The Mobility on Demand Laboratory Environment Project

In the Innovate UK funded Mobility on Demand Laboratory Environment (MODLE) project we are demonstrating that a data- driven approach is able to identify demand and model travel patterns. The MODLE platform has at its core an agent-based model which takes into account commuting patterns and supports the operation of an SME which delivers mobility on demand services in areas with inadequate PT services.

The choice of using an ABM has been led by the capability of representing end-to-end users' journeys using daily activities rather than disconnected trips. Moreover, a flexible demand mobility service cannot be represented as a traditional private hire service because there is no route or predefined timetable which is fully representing the operation of the service.

The ABM has been built using the open source platform MatSim, a strategic multi-agent micro-simulation model, based on a synthetic population which reflects real choice and needs from users. Mobility services are easy to activate and can adapt to the need of users but how to identify demand in advance without incurring in local bias is a challenge.

In the MODLE project, the service prior of the start of the trial was modelled. Performance data and users' requirements are collected using a mobile phone app developed by the company ESOTERIX, who is operating the DRT services. Data collected are then used to improve the simulation of the service or to change the service itself to achieve a better performance.

The area of interest is a regeneration area in the north of Bristol (UK), where lots of industrial park and distribution centres are located. There is a poor network design, legacy of previous land use and a high level of congestion. In North Bristol, up to 75 per cent of employees commute in single occupancy vehicles, with very little alternatives and accessibility option for commuting. Moreover, it is expected an increase of 14,000 new jobs in the area by 2030.

Poor accessibility, the provision of public transport mostly unaffordable, inappropriate to satisfy their needs and the increase in congestion and lack of parking led to unsustainable growth and poor quality of life for commuters, leaving jobs unfulfilled.

To study the introduction of DRTs is pivotal to have up to date data which reflects the actual situation. Census was collected in 2011 and other source of data are limited to small samples which are not normally collected specifically for the area.

In the MODLE simulation, demand and travel behaviours are informed by MND, which reveals real patterns from users (OD matrices and trip chains).

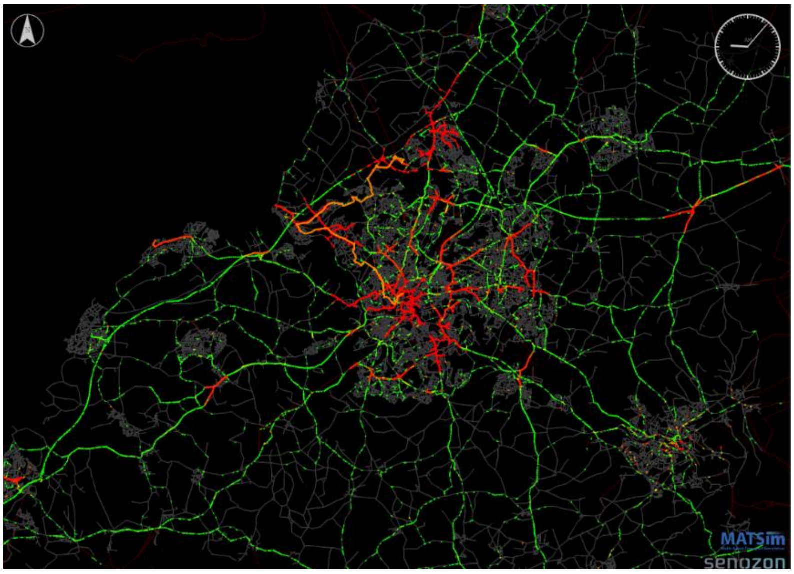
To best inform the service, MND are at a higher spatial granularity in the area of interest for the service and two datasets have been analyzed: trip chain information and trip-based origin destination matrices.

The main aim of the MODLE agent-based model is to assess the impacts of the proposed ride-sharing service on a multimodal network; to understand how demand model will change once the service is active; which modal shift can be achieved, and what is the impact on the public transport services operating in the same area. Other impacts, such as improvement in accessibility to employment and services, increased number of longer journeys made sustainably, reduction of congestion will be assessed.

In figure 1, a visual representation of the model for Greater Bristol in UK, with Bristol City in the middle and the city of Bath on the right-hand side. The model extends for the entire region of the South West of England, since many users were commuting in Avonmouth, in the north-west corner of Bristol, from far away.

The SeverNet Buzz Flyer is an e-hailing minibus service that will improve mobility in the area of Avonmouth with poor accessibility and strongly relying on private cars. The catchment area of the service is north of the river Avon and north of the A420 in the east, however, the model extends to Greater Bristol, which comprises Bristol City, South Gloucestershire, North Somerset, Bath and North-East Somerset (see figure 1) to take into account all the commuting patterns.

Figure 1. Greater Bristol MatSIM Model extension

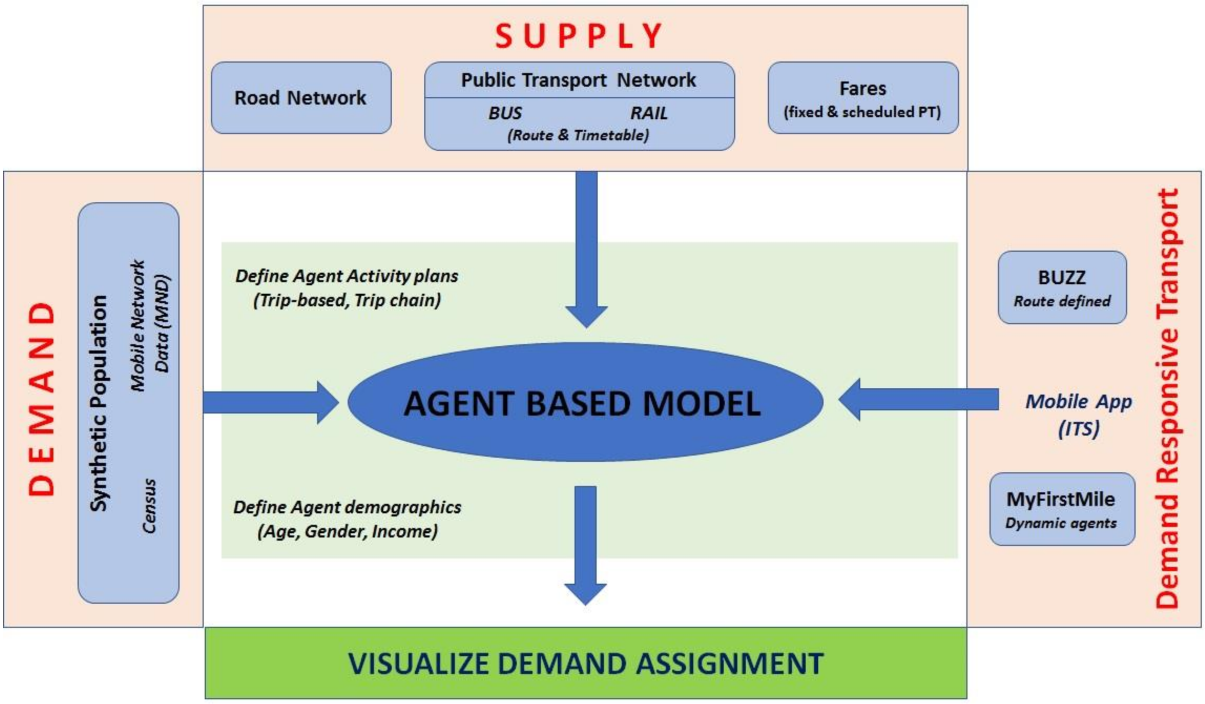


IV. THE MODLE MATSIM MODEL

METHODOLOGY

The agent-based model was built using the open source software MatSim and publicly available data have been used to populate the static information in the software. As described in figure 2, 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[7] which included 340 bus services, with routes and timetable. Bus stops and train stations are loaded from the National Public Transport Access Nodes (NaPTAN[8]) database from the UK Department for Transport [35]. Rail services have been downloaded from Association of Train Operating Companies (ATOC[9]) [36]. Average fares structure was generated looking at First Bus Group fares, who is the main operator in the city of Bristol. This information represents the infrastructure available and the fixed scheduled public transport services currently available and not able to satisfy the demand in the Avonmouth area. The flexible demand service will attract the unsatisfied demand.

Figure 2. Modelling framework



Demand Generation from Mobile Phone Network Data

The users of the service are represented by static agents in the MatSim model. Each of them has a schedule which represents their activity plain over a day. Agents and schedules have been created using anonymized and aggregated Mobile Phone Network Data, created using four weeks of data from a neutral month (March 2016) to represent an average weekly day.

A finer resolution, matching the Lower Super Output Area (LSOAs) in the city of Bristol was used for the Buzz area, whilst Middle Super Output area was used for the Greater Bristol. The aggregated output is a trip-based origin destination matrix, based on data at LSOAs and Lower Super Output Area

[7] TravelLine Dataset available at https://www.traveline.info/ (accessed 22/07/2018)
[8] NaPTAN Dataset available at https://data.gov.uk/dataset/ff93ffc1-6656-47d8-9155-85ea0b8f2251/national-public-transport-access-nodes-naptan (accessed 22/07/2018)
[9] For more information on the ATOC timetables: https://www.raildeliverygroup.com/media-centre/press-releases/2016/469771023-2016-10-21.html (accessed 22/07/2018)

(MSOAs) areas. Since MND are collected in a continuous way, the matrix will also include NUTS1[10] (all areas outside South West of England)) and NUTS3 (regions around the area of interest) trips taking into account need for travel outside the area of interest[11].

Table 1. Population and household thresholds for SOAs in England and Wales

Geography	Minimum population	Maximum population	Minimum number of households	Maximum number of households
LSOA	1,000	3,000	400	1,200
MSOA	5,000	15,000	2,000	6,000

Demographics information (i.e. age, gender and income) are collected from Mobile Phone Network Data as well. This is possible using pay monthly contracts and expansion factors are applied by the network provider directly. Missing information from MND was recollected assuming that the demographics will be aligned with Census trends.

Two datasets have been acquired by the network provider to generate static agents.

The first one is made of trip-based Origin Destination matrices where information on mode of transport and purpose of the trip is known. Only two modes of transport are available: rail and road. Road users are inclusive of drivers and passengers and no distinction can be made between private and public transport users. Static agents are divided in car drivers, car passengers and PT users.

Matrices are available for four-time periods (morning and afternoon peaks, inter peak and off peak) and three trip purposes (home bases work, home based other and not home based) which are associated to inbound and outbound trips.

Since trips are not connected between each other, the use of the trip-based dataset generates one agent for each trip in the dataset (1,900,000 agents in total) with increase of computational power. The simulation generated would be useful to understand traffic flows in the network, but it will be unable to deliver a comprehensive understanding of the users' travel patterns.

The second dataset, also available at LSOA and MSOA areas, maintains trip chains information. The trip chains dataset informs on how many trips are done in a day (from 1 trip up to 12 trips in a day) in any journey from aggregated users. The total number of agents generated with this dataset is 722,752. However, to comply with GDPR regulations, data are further anonymized. Journeys were divided in Return Journeys (starting and finishing in the same zone) and Not-Return journeys. Very little assumptions can be done on the not return journeys, but assumptions have been created for the 68 per cent of journeys which are Return journeys.

Assumptions need to be made to assign a purpose and mode to the trips in the journeys. We have used Structured Query Language (SQL) queries in ArcGIS software to cross reference information from land use and facilities.

Moreover, for the purpose of building activity patterns, each trip chain is associated to more detailed time periods, which gives a higher precision in the temporal distribution of the activities. Each time period is made of three hours and interpeak periods are three, one in the morning (Interpeak1), one in the early afternoon (interpeak 2) and one in the evening (interpeak 3).

Schools and train stations and other facilities have been included in the map to identify the purpose. School runs are identified when trips are made in Interpeak 2. More challenging is to identify trips towards primary schools since they qualify as short trips and generally located within the same census area, hence these trips are not captured in the MND.

[10] NUTS stands for Nomenclature of Territorial Units for Statistics (NUTS) and is a European standard for Census areas.
[11] Lower, Middle and Super output areas is the standard adopted by the Office for National Statistics in UK.

To identify purpose of each leg in the trip chain dataset, the following assumptions have been made. For Return trips, starting and finishing in the same location, it is assumed that the trip is home-based. For all intermediate trips, land use mapping was used to identify type of facilities in order to improve the purpose classification. However, since MSOA and LSOA can be quite large it is difficult to identify purpose of a mixed-area (where residential, commercial and industrial facilities are coexisting).

Time when the first trip started and land use, and facilities (school, shopping malls, train stations and Park and Rides) helps in identifying the purpose of each trip in the journey. Manual checking and visualization of the trips has improved the rules for each clusters of trip chain categories.

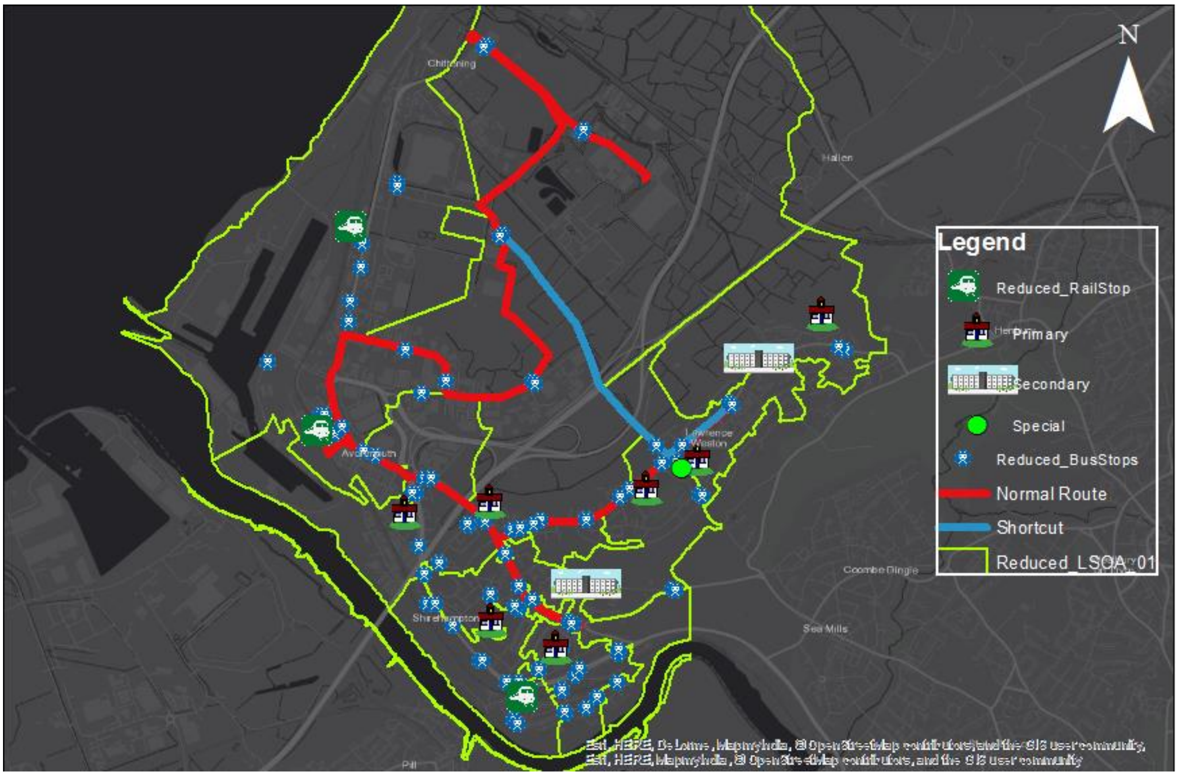
The implementation of the flexible mobility service

The SeverNet Buzz flyer (13 services and 200 users across different businesses) has been launched in August 2018: the service is available to workers in the companies that registered for the service. When the employer subscribed to the DRT service, users travel for free. Service is also open to occasional users who pay 1.50£. Service is pre-bookable from an online portal, hence route is defined on a daily basis.

To analyze the demand and run the simulations quickly a reduced area at the higher resolution LSOA has been chosen (Figure 3). Running on a reduced size area (Severnet Buzz Flyer catchment)

Total number of agents for the reduced area is 32,902 which represents journeys 22,940 in the trip chain dataset.

Figure 3. SeverNet BUZZ service routes



The BUZZ service is modelled as a private hired bus service in Simulation 2 described in the following paragraph.

A deeper analysis of MND has been carried out to understand in which areas people will be keener to shift to the shared service (usually residential areas in the proximity of the industrial park) and where people will be more likely to use the service as a first mile and last mile service in integration with the fixed scheduled public transport.

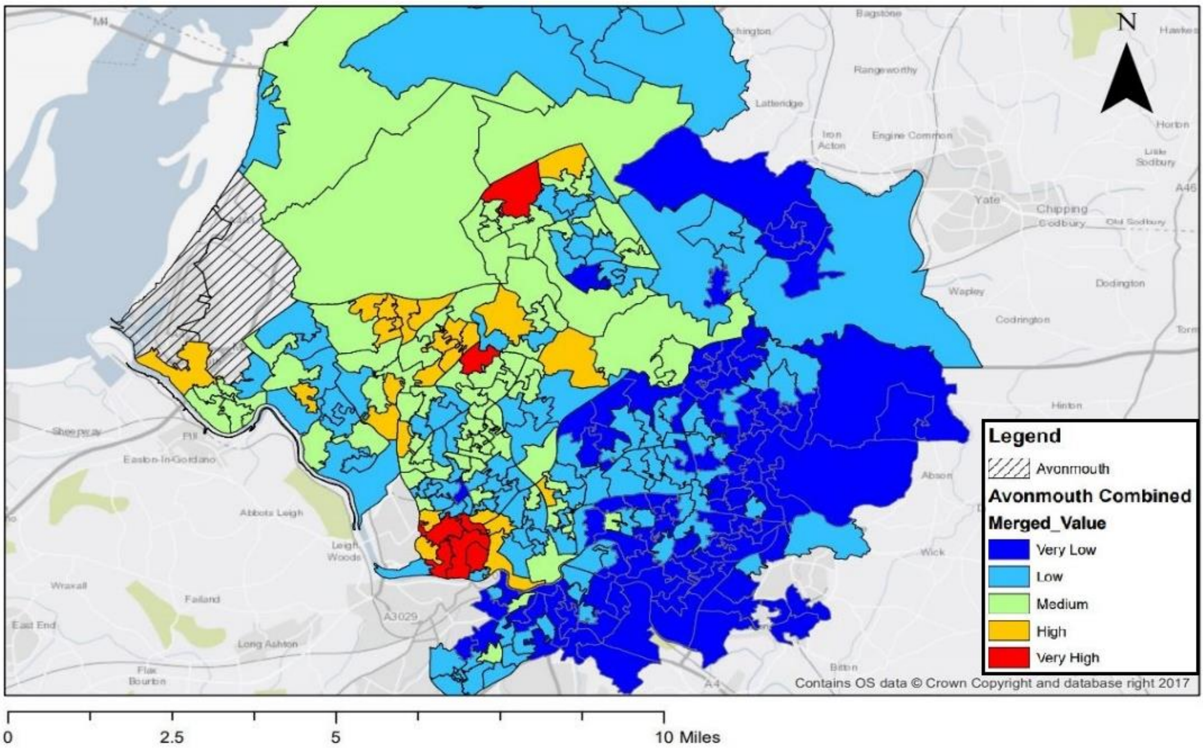
At the end of this analysis, the different level of aggregation in the MODLE area (LSOA, MSOA, NUTS1 and NUTS3) also identified travel patterns and distance travelled with many users travelling from outside the region (mostly from London). In figure 4, darker areas represent the zones of origin where is more likely people will be keen to use the service. The map represents a combined index of number of trips generated/attracted and density of population in the zone, but information on the journeys and how their distributed over the day are not given.

For example, looking at trips between Avonmouth and the city centre of Bristol, a high number of trips which were not explained by local knowledge was revealed. Insights from the trip- chain datasets revealed journeys with a high count of trips in a single day, mainly concentrated in the early morning and morning interpeak, which is linked to journeys due to logistics and distribution.

Avonmouth routinely attracts the inbound and outbound journeys to the residential area of Staple Hill and the UWE campus areas of Frenchay and Glenside. Most journeys to and from the industrial area of Severnside come from the South Gloucestershire areas Thornbury South and Alverston, and Patchway. Most Journeys to and from Avonmouth are to the Bristol suburbs of Cabbot and Henbury.

For the rail mode, all of the different areas investigated attract the majority of rail trips from NUTS areas. Park and ride trips are also included in the travel counts. The number of inbound and outbound rail journeys in Frenchay is approximately 3.8 times higher than in the other four areas combined.

Figure 4. Demand for the Buzz service in Avonmouth



A deeper analysis of MND in the Buzz service has been carried out to understand which areas are where people will be keener to shift to the shared service (usually residential areas in the proximity of the industrial park) and where people will be more likely to use the service as a first mile and last mile service to the fixed scheduled public transport, either bus or rail.

At the end of this analysis, the different level of aggregation in the MODLE area (LSOA, MSOA, NUTS1 and NUTS3) also identified travel patterns and distance travelled, that most people were travelling from outside the region (mostly from London).

Demand in the MatSim model is generated with the creation of static agents, which must fulfil their activities in a timely manner otherwise will be penalized by the model. The scoring they receive will affect the following iteration: a negative score will produce a change of plan in the agents, either a change of routes or schedules in the activities, according to the innovation strategies specified in MatSim:

- ChangeExpBeta, changes between plans with a configured probability (70 per cent)
- ReRoute, searches for alternative routes other than the shortest path (10 per cent)
- SubtourModeChoice, changes mode of transport (10 per cent)
- TimeAllocationMutator, shifts activity end times randomly within a configurable range (10 per cent).

We run several simulations for the purpose to assess different data input to generate the daily plans for the agents. Simulations and the base case scenario have been built to explore the difference between different methods for agents' generation:

- *Simulation 1*: data input from OD assignment matrices from the Greater Bristol model built with the commercial modelling tool Saturn
- *Simulation 2*: static agents have been generated using anonymized and aggregated Mobile Phone Network Data, using trip-based OD matrices for Road and Rail mode and for 4-time periods
- *Simulation 3*: agents generated using trip-chain dataset and 6-time periods. Enhanced dataset will comprise purpose and mode

V. RESULTS FROM SIMULATIONS

We explored several solutions to understand the potentiality of the data input and the results that can be achieved with different data granularity. The first dataset to be used as input data was the travel to work data segmented in three times periods: Morning, Evening and Interpeak. The activities are home, work, and other. All the agents are employed and contain information about gender and age. The Greater Bristol network is loaded with 352,739 agents traveling by private car and bus. The simulation required two days to run on a machine with 40 CPUS and 200GB of RAM.

In the second simulation, the synthetic population was built using anonymized and aggregated MND to generate static agents and provide information on demographics (gender, age and income) and travel patterns at LSOA for MODLE area or MSOA level for Greater Bristol, using trip-based OD matrices per each mode of transport and per each time period.

This has generated 1.9 million agents, since no trip chain was maintained, leading to a highly congested network. Moreover, MND are only able to provide information on road transport or rail, so any information on how many passengers are in private cars or public transport was missing. Occupancy on public transport was created using the Trip End Model Presentation Program (TEMpro) software from Department from Transport in the UK.

To represent the end-to-end user journey, data input was changed in trip chain dataset for the third simulation. Using the new data input format, the end-to-end user journey is retained, and the number of static agents dropped to 722,000 for the Greater Bristol area.

The run time was reduced creating assumptions on purpose and mode of travel so that many activities were time bounded.

The strategy module used for the scoring mechanism contains the following weights:

- BestScore, choose the previous iteration's plan (80 per cent)
- ReRoute, searches for alternative routes other than the shortest path (10 per cent)
- SubtourModeChoice, changes mode of transport (10 per cent)
- TimeAllocationMutator, shifts activity end times randomly within a configurable range (0 per cent)

The Buzz network was introduced as a fixed route service and defined as private transport publicly available. Several iterations were run to establish the cost of the service and the uptake of the Buzz service when the cost to access is varied.

Results shown a modal shift of 2 per cent from private cars with a 30 per cent increase in the use of public transport services (both rail and bus). This was explained by the fact that people were travelling from other areas and the presence of the DRT has increased the accessibility of the Avonmouth area located in the north of Bristol (UK). Maximum number of people which is attracted by the service is 500 users, which is in line with the growing number of subscription to the service.

CONCLUSION

Mobility on demand services will be extremely useful in future to provide the first/last mile service in a fully connected and integrated transport systems under the Mobility as a service wide vision.

The use of agent-based models (ABMs) is largely unexplored in the transport sector, but with the increase of computational power and data fusion techniques, mobility services operation and mobility on demand can be considered even if no routes and timetables are specified in the model.

This provides local authorities and central governments with a tool that is able to quantify the impact of the introduction of private mobility on demand services and quantify the integration with the mass transit, allowing the reorganization of public transport services which is reducing operational costs on less profitable corridors.

The main focus of this application is to develop an open and accessible tool for consultants, Local Authorities and even operators to assess the potential and associated impacts of the integration with mass transit of Demand Responsive Transit (DRT) with existing or new fixed schedules public transport services. This is particularly of interest for regeneration of urban environments or for rapidly growing cities such as in the case of Asia-Pacific cities region.

The work presented in this paper is part of the Innovate UK funded MODLE project aiming at exploring the introduction of mobility services in areas currently served by inadequate public transport to meet current demand and users' needs. The case study proposes to model mobility services ahead of the launch using an agent-based model, to identify the demand and assess the performance and impact of the services in corridors of interest for the operators and the Local Authorities. The output of the model is a powerful visualization of users' travel patterns which highlights bottlenecks and congestion hotspots and specify how many users are going to utilize the new service.

The visualization tool, integrated with the ABMs, is very intuitive to communicate to policy makers and stakeholders from different backgrounds the hotspots and where the pain points are in the road network.

The data-driven approach provides assurance on real travel patterns and commuting habits at a regional scale, which goes beyond the administrative boundaries of strategic transport models and provide a comprehensive picture that takes into account rail and road modes.

Also, the generation of a synthetic population using an activity-based model to generate daily plan for agents using MND is not a standardized process but provided the possibility to explore commuting patterns in areas where historical data were limited due to the change of the activities in the areas. MND are collected continuously by the network providers, hence the data always reflect the actual demand available when the service has to be launched.

Main focus of the model was representing the integration with fixed schedule public transport service (Rail and Road) to demonstrate full integration of public transport with private mobility services. The open platform MatSim used to build the Agent based model was used to model and visualize demand for the proposed flexible demand responsive transit.

Results from simulations show that a higher granularity and trip chain dataset provided better insights of travel patterns and in the number of agents generated by the model. We have compared the performance of the model using both trip-based and trip-chains dataset and we have found that the trip-chains datasets, which retains information on the sequence of trips over a day, creates a reduction from 2 million trips to 722,000 journeys for the Greater Bristol area. This led to a quicker running time of the model but also to a greater understanding of travel patterns from users and to whether or not to deploy the DRT in an area. The Buzz service simulation highlighted that DRT works better in integration with fixed scheduled public transport services with a 30 per cent increase in patronage and a 2 per cent modal shift from private cars. Different prices were tested for the uptake of the service.

However, further work is needed to identify external factors that might affect the uptake of Mobility on Demand service. This quantitative information can also be considered and specified in agent-based models.

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