Integration of Demand and Operational Models for an Agent-based Model of a Stackable Electric Vehicle.

Haitam Laarabi[1], Chiara Boldrini[1], Raffaele Bruno[1], Peter Davidson*[2], Rob Culley[2], Helen Porter[2]
1. IIT-CNR, Via G. Moruzzi 1, Pisa – Italy
2. Peter Davidson Consultancy Ltd, Berkhamsted, UK, peter@peter-davidson.com

Abstract. This paper describes a novel agent-based demand modelling framework that applies discrete choice techniques to forecast car sharing demand by considering the influence of individual preferences, behaviours and lifestyles in the utility associated with each transportation alternative. A population synthesizer is used to create a population of synthetic agents, whose individual decisions are each determined by discrete choice modelling. Then, the agents' travel plans are provided as inputs to an an operational model of a car sharing system developed in MATSim. To validate the effectiveness of our modelling framework, we have applied it to a suburban area of Lyon. This model is described in detail here and preliminary results are given.

KEYWORDS:
Car sharing, discrete choice modelling, agent-based simulation, behavioural response

1 Introduction

Car sharing has been gradually developing over the past two decades and nowadays it is established as one of the most relevant shared-use mobility services for smart cities. With car sharing, car access is decoupled from car ownership: people do not own a car, they simply rent it from the car sharing operator when they need it, typically for short-range trips. In cities where car sharing services are running, positive effects have already been measured: car sharing members use cars less, rely more on public transport or bicycles, and in some cases, they even renounce their car ownership [1].

The objectives of car sharing schemes in terms of reducing car ownership and related problems are clear, but implementation of any such project is expensive and requires a proven business case. In particular, users' behaviours result in spatial imbalance of the fleet of shared vehicles, which tend to accumulate in commercial/business areas in the morning and in residential areas at night [3]. Thus, the balance in the distribution of shared vehicles during the day must be guaranteed through a relocation mechanism, and three main classes of vehicle redistribution policies have been proposed: autonomous vehicle based strategies, operator- based strategies and user-based strategies. It is important to point out that the relocation process is intrinsically inefficient: as one driver per car is needed, to relocate several cars a large workforce or many willing customers are necessary. This significantly complicates the relocation with respect to, e.g., bike sharing services, where a single worker with a van can redistribute a large number of bicycles. To address this issue, the **E**asily di**S**tributed **P**ersonal **R**ap**I**d **T**ransit (ESPRIT) European project aims at prototyping a new concept of stackable electric car that can be driven in a road train of up to 8 vehicles, which has the potential of enabling more efficient redistribution of fleets and a cost-efficient car sharing service[1]. However, both the demand for use as well as the operating costs of the ESPRIT system need to be explored. In particular, understanding the pattern of required redistribution of vehicles as well as the response of the public to using and indeed redistributing an additional vehicle themselves needs to be demonstrated.

To address the above issues, in this paper we will describe a novel agent-based demand modelling framework that applies discrete choice techniques to forecast car sharing demand by considering the influence of individual preferences, behaviours and lifestyles in the utility associated with each transportation alternative. A population synthesizer is used to create a population of synthetic agents, whose individual decisions are each determined by discrete choice modelling. This will include decisions about the scheduling and locations where activities are undertaken, as well as longer term lifestyle decisions such as where to live and work. ESPRIT journeys made in conjunction with Public Transport services and purely by ESPRIT are considered as separate modes within the model. Application of a Monte Carlo process allows the calculated probabilities to be translated to binary decisions, so that the decisions made by each agent can be passed to the agent-based transport simulator as a set of travel itineraries, one for each agent [3, 4]. Attributes of the individual agents are carried through the choice model, so that travel decisions are added to the synthetic population as it is processed by the demand model. We developed a computationally efficient process by which each agent is modelled in turn, reducing run times compared to processing all the agents in one go. Then, we have combined the car-sharing demand forecasting engine with an operational model of the ESPRIT system that has been developed in MATSim, and described in a prior work [5]. Our simulation framework allows to analyse different categories of cars sharing services, such as hybrid systems where both one-way and free floating modes coexist. The integration between the demand model and the supply model is based on a skimming process that provides generalised travel costs between all zones, so that congestion effects that slow down traffic can be used in determining the demand for ESPRIT. Note that both demand and supply models can be iterated to achieve convergence. Furthermore, we have developed an offer model that offers a set of alternative ESPRIT packages of use to each agent defined by a price and a particular pick up and drop off location for the ESPRIT vehicle. By offering an attractive price agents can be incentivised to use ESPRIT so that the system is kept in better balance. Agents may be offered an alternative in which they tow a second ESPRIT vehicle behind them to contribute to vehicle relocation.

To validate the effectiveness of our modelling framework, we will apply it to three case study areas, the first of which is a suburban area of Lyon. This model is described in detail here and preliminary results

[1] http://www.esprit-transport-system.eu/

are given. The second area is a business park in Glasgow, and in this version lifestyle decisions such as whether to move house, will be included. The third case study area is L'Hospitalet in Spain.

2 Overall Model Structure

The overall model consists of a demand and supply model which interact with a business case model tool. Figure 1 shows the links between the models. The operational model is an agent based model that is used to optimise the deployment of charging stations for the vehicle and to develop efficient strategies for recharging and redistributing vehicles. A synthetic population of agents each undertakes a set of daily activities and the model determines where the agent does the activity and the mode of transport used. However, the accessibility and availability of transport affects where people choose to live, as well as the activities they undertake and how they are scheduled, and so the demand model is being developed to take account of these wider choices.

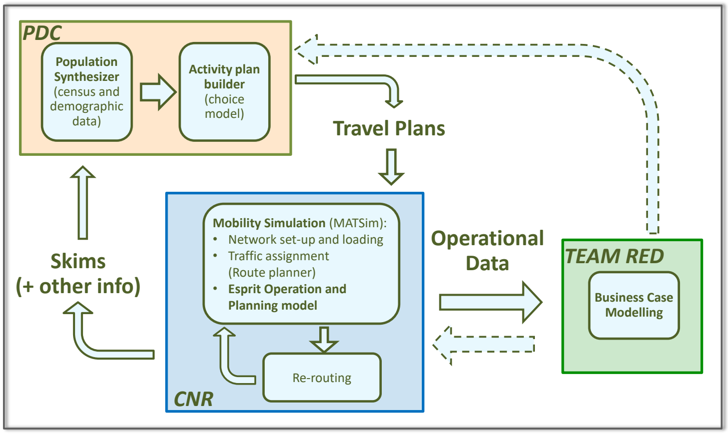

Figure 1: Interaction of model components.

2.1 Population synthesizer

The population synthesiser creates a synthetic population whose characteristics match the known attributes of the actual population according to available census data, Typically, census data gives the attributes in the form of "control totals" with respect to a specific zone system. The attributes included in our model are:

- Household size
- Tenure type
- Car ownership level

Household and travel diary surveys give information about households, individuals and trips made. Households can be sampled from the survey data and for each zone in the zone system a set of household records can be created with overall characteristics matching the control totals. The individuals associated with the household records, and their associated activities determines the agents and their activities.

Each agent is associated with a set of demographic data that was determined by the survey interview, for example age band and whether they can drive. These attributes potentially affect the choices that the agent makes, for example if they cannot drive then they will not be able to drive an ESPRIT vehicle.
The households in the survey data are between particular origin and destinations, but the sampling process allocates households to zones which will be different to the actual zone that is relevant to the individual trip. For this reason, the homes are adjusted to match the zone relevant to the synthetic population.
The destination location will similarly be irrelevant, but the choice model uses destination choice to determine the trip destinations rather than using information on the trip record.

2.2 Choice nest

Conventional transport demand modelling is based on trip matrices representing the number of trips between an origin and destination zone, for a given market segment and time period. Here we use individual agents and trips so that results can be transferred directly to the operational model which uses simulation techniques applied to individuals.

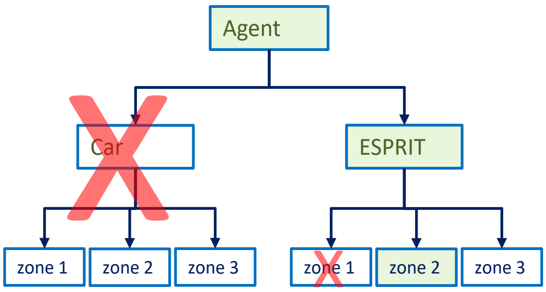

Figure 2: Example of how alternatives are removed (simplified version of the full choice nest).

The probability of a decision is calculated using a logit based approach. For destination choice, this would mean that the probability of a trip from a particular origin zone to every destination zone in the model is calculated. Without the agent based implementation, the probabilities would be multiplied by the number of trips starting from that origin zone, and it would not be possible to trace an individual trip. In the agent based approach, Monte Carlo sampling is applied to pick a single destination so that an actual trip is modelled. Monte Carlo techniques choose the outcome based on random sampling, but weighted according to the calculated probabilities. This is similar to rolling a loaded dice.
This agent based approach can be very computationally efficient compared to conventional transport models because each agent can be processed individually without the need for large memory requirements associated with market segmentation.
The full version of the model should include some lifestyle behavioural choices relating to longer term planning as well as the day to day choices about scheduling activities and linking trips into tours, taking account of the needs of, for example, children being escorted to school.
The mode choice element includes the following modes:

- Private car
- Park and Ride
- Public Transport
- ESPRIT (no Public Transport)
- ESPRIT followed by Public Transport, “ESPRIT first”
- Public Transport followed by ESPRIT, “ESPRIT last”
- Walk

ESPRIT first and ESPRIT last match to the concept of “first and last kilometre”. These trips are of particular interest. Individual agents make travel choices according to whether they have a driving licence, and whether there is car belonging to their household. If they can drive and have access to a car then all seven modes are available, but if the household does not have a car they may still choose to use ESPRIT. The choice nest takes account of their car availability status and directs the agent through the appropriate part of the choice nest accordingly.

2.3 Travel Plans for individual agents

The output of the choice nest is translated into a series of trips, or travel plans, for each agent, that can be interpreted directly by the MATSim model.


```xml
<!--=======================================================-->
<person id="p_677_405">
  <plan selected="yes">
    <act type="home" facility="HO_080_008" x="852585" y="6521419" end_time="08:39:00" />
    <leg mode="carsharingDirectTrip" />
    <act type="interchange" facility="E450" x="851985" y="6521017" start_time="08:42:00" max_dur="00:00:01" />
    <leg mode="pt" />
    <act type="work" facility="WO_117_001" x="849381" y="6521883" start_time="08:58:00" max_dur="05:30:00" />
    <leg mode="pt" />
    <act type="interchange" facility="E450" x="851985" y="6521017" start_time="14:48:00" max_dur="00:00:01" />
    <leg mode="carsharingDirectTrip" />
    <act type="home" facility="HO_080_008" x="852585" y="6521419" start_time="14:51:00" max_dur="00:30:00" />
    <leg mode="car" />
    <act type="leisure" facility="LE_085_002" x="853156" y="6520096" start_time="15:30:00" max_dur="03:10:00" />
    <leg mode="car" />
    <act type="home" facility="HO_080_008" x="852585" y="6521419" start_time="18:48:00" />
  </plan>
</person>
<!--=======================================================-->
```


Figure 3: Travel plan extract.

Trips that are not considered to be involved in the study area are removed from the demand model output; that is trips that neither start or finish in the study area, are discarded unless they are likely to pass directly through the study area. Typically, the final number of agents passed to MATSim is about one hundred thousand, and for each of these agents a travel plan is prepared. This necessitates adding coordinates for home and destination locations, as well as the time the agent leaves home and arrives at each destination. The overall process of writing travel plans represents turning the outputs from a strategic demand model into input that can be used by a microsimulation tool. This linking the two types of models in an innovative procedure that is made possible by the use of agents in the demand model. Figure 3 shows an extract from a typical travel plan.

Park and Ride and ESPRIT first and ESPRIT last combine trips on highway and Public Transit routes, which can be problematic to simulate in MATSim. To allow the agent to be handled on both types of network in MATSim in a simple manner we have introduced the concept of "interchange facility" where an agent can instantaneously pass from ESPRIT mode to Public Transport mode and vice versa. More precisely, the location of the Public Transport station is assumed to be the place where the interchange takes place and it is explicitly noted in the travel plans for these modes (see Figure 3).

The demand model uses zones are defined by geographic boundaries plus a zone centroid, and the choice model outputs trips between pairs of zone centroids. If these locations were translated directly into movements of agents they would be unrealistic and would create severe bottlenecks because the origin and destination of every trip would be condensed to a few locations. Instead we have identified a group of facilities for each zone and a random function allocates the agent to a home facility and a destination facility that matches the trip purpose of their journey.

The travel diary that is used to create the synthetic population gives the time the agent leaves home. This time is carried through to the travel plans, but the journey times to the destination location are calculated from the skims. The time spent at each location by the agent is also known from the travel diary, and these durations are unchanged by the plans writing procedure.

Currently the demand model works with home based trips, and in order to complete the tour, the plans writer reverses the trip to return the agent home.

2.4 Car sharing module

The car sharing model for MATSim was been firstly described in [5]. For the sake of clarity, we briefly present a summary of the key features.

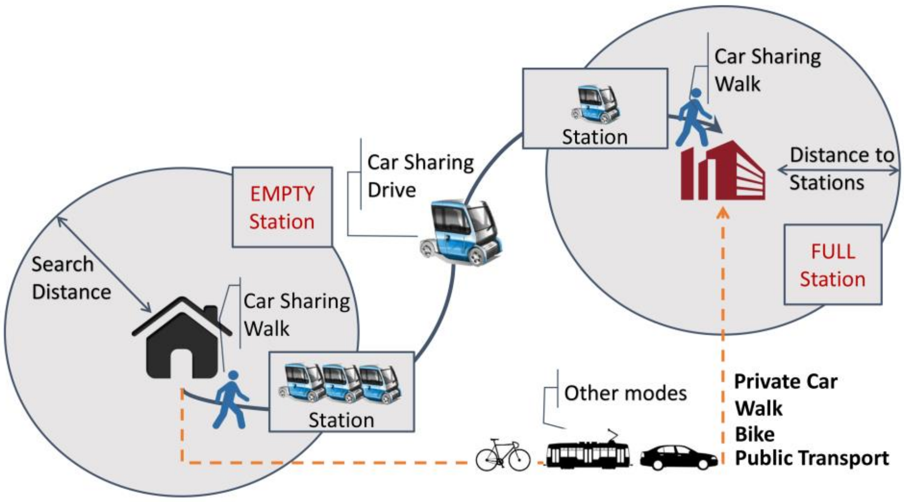

Figure 4: Graphical representation of the simulation model of the car sharing model (one-way case).

In the case of one-way car sharing service, the simulation model is illustrated in Figure 4 and summarised by the following steps:

Booking Vehicle: after the agent finishes an activity, it starts looking for the closest station, within a search distance radius, that has an available (i.e., non-booked) vehicle. If an available vehicle is found then the agent books it, and this makes the vehicle immediately unavailable to other agents;

1. Access Walk: agent walks from its current location (e.g. home) to the selected station;
2. Pick Up: agent picks up the vehicles and frees the parking spot;
3. Booking Spot: agent looks for the closest station to his final destination with an available parking space and books it, which makes the spot unavailable for others;
4. Drive: agent drives the vehicle to the destination station while interacting with other vehicles on the network;
5. Drop Off: Agent drops off the vehicle on the booked spot, which terminates
6. the rental period;
7. Egress Walk: agent starts walking towards the location of his next activity;

Finally, agent carries out the remaining of the daily plan. In case of neither a vehicle is available nor a parking spot has been found, the agent aborts its plan and consequently the controller assigns the worst score to the plan. The individual can also decide to use other modes such public transport, bike or private car.

2.5 Skimming process

The destination choice model looks at the available destinations for each origin, and calculates the generalised cost of each alternative. This generalised cost is used to calculate the probability that that alternative is selected using *random utility model theory* (RUM) consistent with logit choice modelling. In order to calculate a generalised cost the characteristics of every destination from each origin needs to be known for each mode. In conventional network modelling network skims are created at the model assignment stage, whereby these characteristics are recorded. The skims will vary between iterations, because as roads become more or less congested, so travel times change. In this model, the skims were produced by MATSim by recording the characteristics of every alternative as well as the alternatives finally selected.

ESPRIT first and last trips (and Park and Ride trips), involve travel by an agent on both highway and Public Transport routes. In order to create skims for the demand model for these modes, interchange locations were introduced at the five tram stations within the case study area. The MATSim skims were calculated between every interchange and every zone centroid enabling the ESPRIT first and last, and the Park and Ride skims to be prepared by adding the journey characteristics from the zone centroid to the interchange and then from the interchange to the destination zone centroid.

3 Lyon Case Study

The Lyon model is a special case which uses a subset of the full choice nest, due to a lack of robust data and includes mode and destination choice only.

3.1 Description of area

The study area is part of the Greater Lyon area, and consists of three villages: Decines-Charpieu, Meyzieu and Jonage. The area is mainly suburban, with low density housing with an industrial zone to the east of Meyzieu.

3.2 Zone system

The study area consists of 93 zones with a further 51 zones across Grand Lyon. The area is served by buses and the T3 tram line which has 5 stops within the study area. Park and Ride is available close to each of these tram stops except at Grand Stade. In addition, RhoneExpress services pass through the area from Lyon airport (which is to the south west of the study area) stopping at Meyzieu Industrial in the study area and Vaulx-en-Velin to the west of the study area.

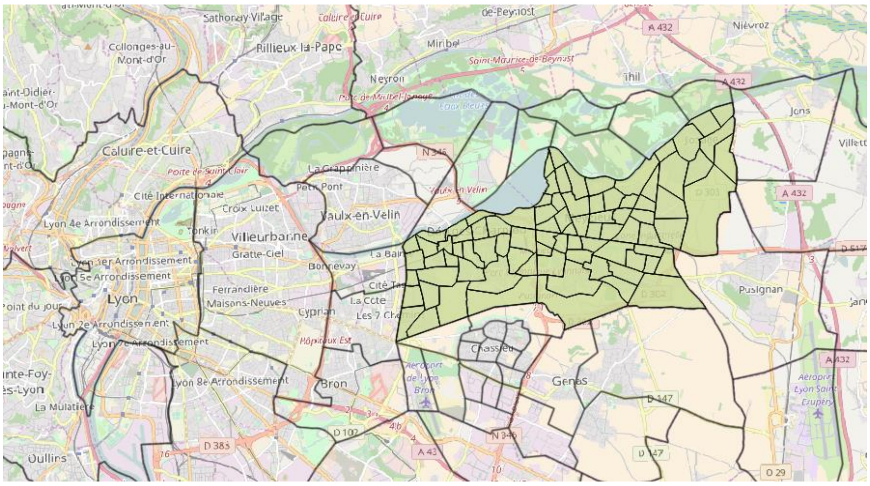

Figure 5: Lyon case study area.

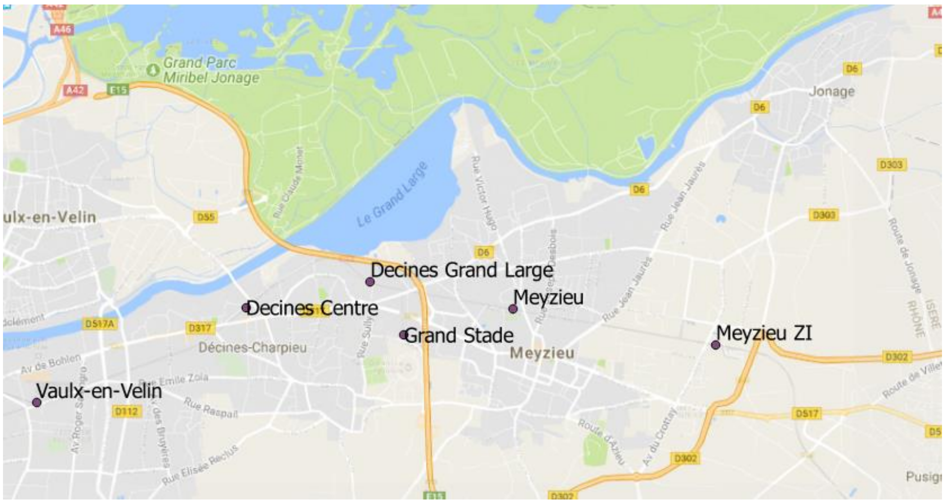

Figure 6: The study area, in detail.

In order to create the synthetic population for Lyon we used census data from the INSEE website. This version of the model also uses data from the Lyon Travel Diary Survey 2015 and we are grateful to Réseau Quetelet for granting permission for us to use the 2015 Lyon Travel Diary survey data (lil-1023 : Enquête ménages déplacements (EMD), Lyon / Aire métropolitaine lyonnaise - 2015 (2015, CEREMA))

The synthetic population is of the order of 1.4 million agents, all of whom pass through the choice model to determine the destination and mode of trips. For this model, the types and numbers of each type of facilities are:

- home, 35,853
- work, 354
- education, 362
- shopping, 402
- leisure, 431

3.3 Calibration

The Lyon Household and travel diary survey 2015 is used to estimated coefficients to use in the demand model. The records were split according to whether the respondent had both a driving licence and the household a car (car available) or not (non car available). The trip records were fitted to a nested mode (Car or PT) and destination choice model, and the coefficients at both levels of the nest were estimated simultaneously.

Figure 6 shows the results for people who have access to a car. The signs of the coefficients of time and fare are both negative indicating, as would be expected, that increasing journey time and increasing fare are both disliked. The value of time can be calculated as the ratio of the coefficient of fare to time, and this is about 5 cents per minute.

The t-statistics indicate how reliable the estimations are; a t-stat of magnitude greater than 2 is considered to be significant, so here all the coefficients estimated are statistically significant. The structural parameter is less than one with a high t-stat, confirming that the choice nest structure is appropriate.

Attributes		**Car Available**
In Vehicle Time	*Coefficient*	-0.068
	t-stat	28
	VoT (euros per min)	0.04
Fare	*Coefficient*	-1.545
	t-stat	8
	relative to time	23
In (Jobs)	*Coefficient*	1.194

	t-stat	16
	relative to time	-17
In (Pop)	*Coefficient*	-0.684
	t-stat	14
	relative to time	10
Internal to Internal	*Coefficient*	-0.050
	t-stat	0.5
	relative to time	0.7
Eternal to Internal	*Coefficient*	-1.404
	t-stat	13
	relative to time	21
Structural Parameter	*Coefficient*	0.272
	t-stat	21
	relative to time	-4.0
Estimated Parameters		8
Observation Used		3.341
Null log likelihood		-18259.9
Model log likelihood		-11944.6
Rho bar squared		34%

Figure 6: estimation results for non car available

3.4 Preliminary results

The simulated scenario as depicted by Figure 7 considers a network of 141.795 links, not only limited to the study area, with 19.186 households, 326 work facilities as well as additional 1.090 facilities for different purposes.

The demand contains a total number of agents of 80.740 agents and a customer base of 6.416 agents. While the modal split as shown in Figure 8, is composed of four main modes: private cars (car), esprit vehicles (esprit), public transport (pt) and walk. Esprit represents 4.6% of the modal share, while private car is leading by a modal share of 57%, then public transport 28.1% and finally walking mode representing 10.3% of the modal split.

Initial results have been obtained under a scenario where 77 stations were deployed (blue diamonds in Figure 7) and the cost of ESPRIT is based on in vehicle minutes only, at 0.27 euros per minute, and ESPRIT use is restricted to journeys covering 500m or more to prevent ESPRIT being used for very short journeys.

Two observations can be drawn from the results below. First the energy consumed (Figure 9) is relatively meagre due to the short distance trips of the small study area. Second the availability graph of vehicles at station (Figure 10) matches to a great extent the esprit activity during the day (Figure 11)

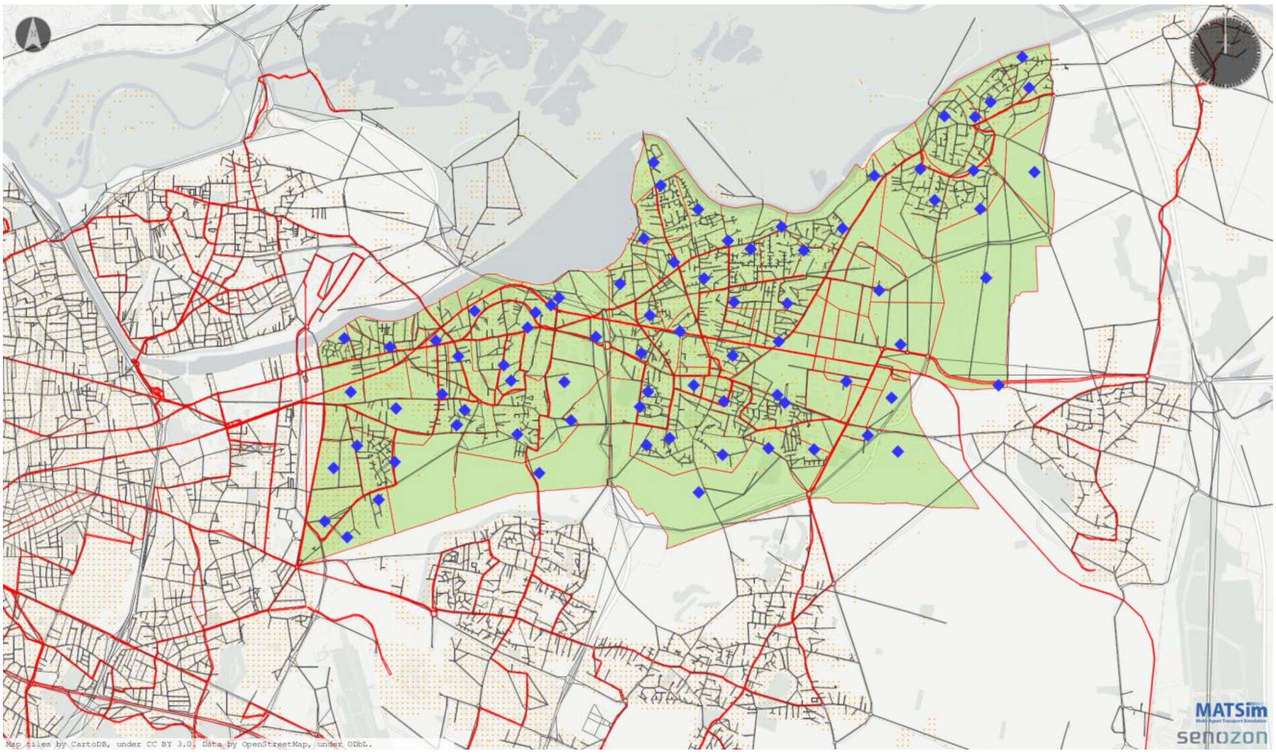

Figure 7: Map of the simulated area, with blue diamond referring to the Esprit stations deployed within the study area. The red lines refer to the PT network, while the grey lines refer to the car network.

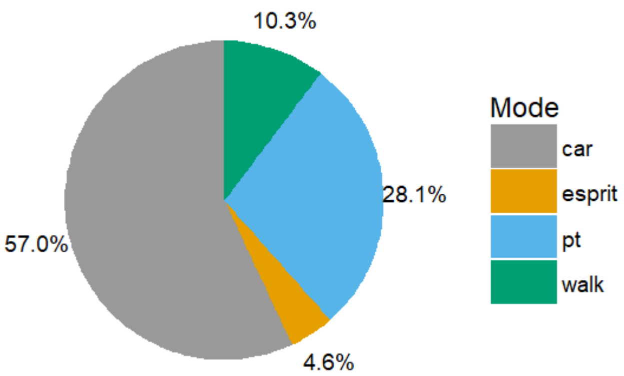

Figure 8: Modal split of the simulated demand

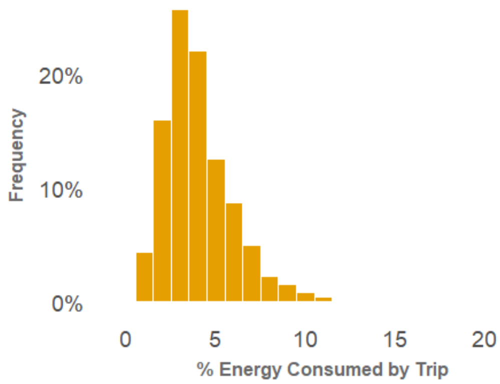

Figure 9: Frequency of energy consumed during the simulated day

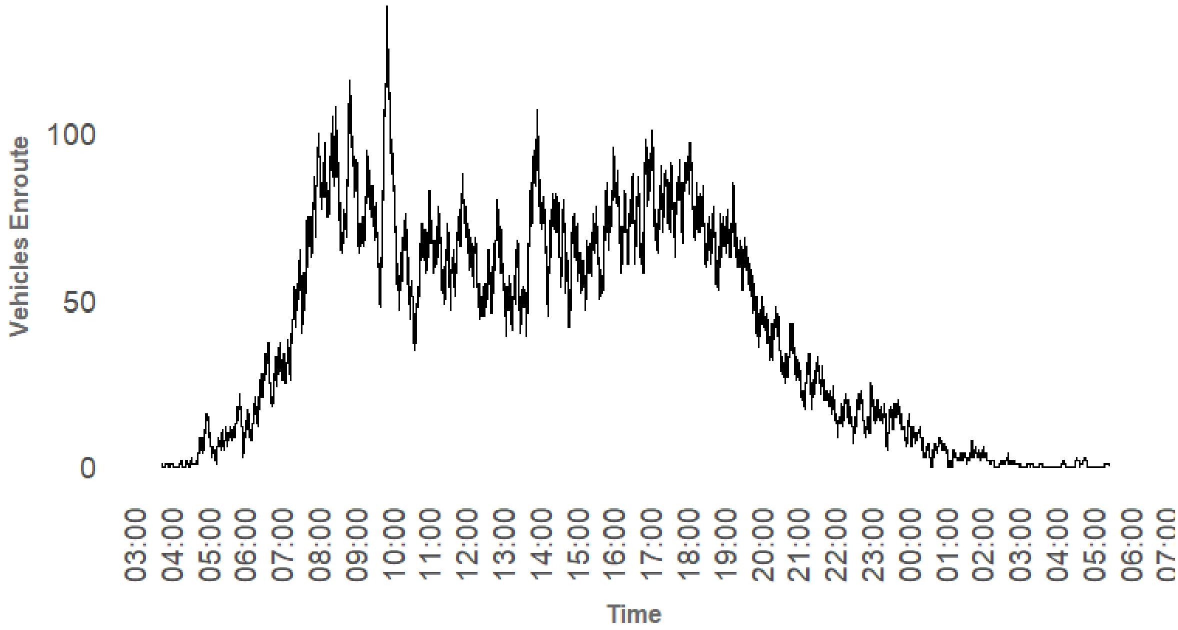

Figure 10: Esprit activity (or En Route) during the simulated day

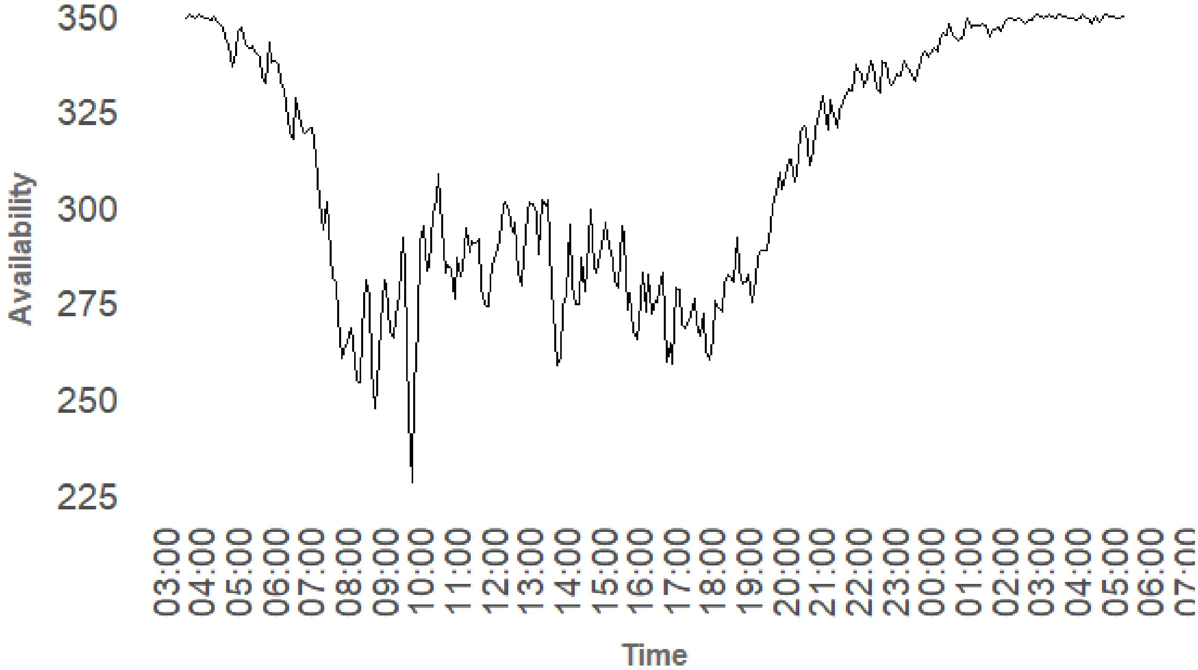

Figure 11: Esprit vehicles availability during the simulated day.

4 Glasgow Case Study

The model uses data from stated and revealed preference surveys, and activity diary data which was collected through a detailed survey of staff working at Hillington Park and households in the surrounding area. The stated preference surveys explored how alternative home and job locations would affect choices of transport used, including an ESPRIT service. The site is particularly relevant for first and last mile travel with ESPRIT because bus and train services are limited to the periphery and central area of the site, with travel within the site poorly served. Lifestyle modelling will complement the household and travel modelling. For instance, a lifestyle change such as moving house will affect all individual agents belonging to that household

References

[1] E. Martin and S. Shaheen, “The impacts of car2go on vehicle ownership, modal shift, vehicle miles travelled, and greenhouse gas emissions: An analysis of five north American cities,” Transportation Sustainability Research Center (TSRC), UC Berkeley, 2016.

[2] C. Boldrini, R. Bruno, and M. Conti, “Characterising Demand and Usage Patterns in a Large Station-based Car Sharing System,” in Proc. of IEEE INFOCOM Workshop on Smart Cities and Urban Computing, 2016, pp. 1–6.

[3] A. Horni, K. Nagel and K. Axhausen, "The Multi-Agent Transport Simulation MATSim", 2016

[4] Davidson P, Sadeghian S, Porter H, “Converting a conventional transport model into an agent based transport model with as much about activities and lifestyle choices as possible.” Presented at the European Transport Conference, 2016

[5] Laarabi M.H., Bruno R. (2017) A Generic Software Framework for Carsharing Modelling Based on a Large-Scale Multi-Agent Traffic Simulation Platform. In *Proc. of Agent Based Modelling of Urban Systems Workshop* (ABMUS 2016), Lecture Notes in Computer Science, vol. 10051.