Electric Vehicle Destination Charging Demand Characterisations at Popular Amenities using Smartphone GPS Data

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Electric Vehicle Charging

A question of energy

- Cars in Britain drove 408 billion km in 2017
- Typical energy consumption ~18 kWh/100 km
- 100% private transport electrification -> ~73 TWh of generation (22% more than last year)

A question of power

- This is much more uncertain...
- When will people charge?
- Where will people charge?
- How will people charge?
The Future of EV Charging?

• Most of the academic literature to date has focussed on a predominantly domestic-based EV charging system

• *Is this realistic?*

Lack of off-street parking  
Lack of *range confidence*  
Changing car ownership
Four Types of Charging

Rapid
- Power > 50 kW
- Charging window < 20 mins

Destination
- Power 10-50 kW
- Charging window 20 mins – 3 hours

Workplace
- Power < 20 kW
- Charging window 3 – 9 hours

Domestic
- Power < 10 kW
- Charging window > 9 hours

Less Flexible  More Flexible
High Power  Low Power
Human Behaviour

- Widespread EV uptake hasn’t happened yet
- It’s difficult to predict how people will behave
- Most of the work to date is based on surveys, which represents peoples’ perception of their behaviour
GPS Data – Google Maps
Popular Times

- Collected from Smartphone users with the Google Maps application (and location history enabled)
- Hourly popularity (= occupancy) (%) data based on ‘peak popularity’ for a given day of the week

+ Captures users’ actual movement patterns
- Constantly changing
- ‘Sample size’ is potentially very large

- No absolute numbers
- No seasonal variation
- Selection bias?
Popular Times data – Shopping Centres

MONDAY
Density plot - 298 shopping_malls, Monday

SATURDAY
Density plot - 298 shopping_malls, Saturday
Popular Times data – Gyms

MONDAY

Density plot - 2211 gyms, Monday

SATURDAY

Density plot - 2211 gyms, Saturday
Using the Data – Arrivals Profile

Arrival rate, $\lambda = \lambda(N,T)$

$P(\lambda) = e^{-\frac{N}{T}} \frac{(\frac{N}{T})^\lambda}{\lambda!}$

Occupancy, $N$

Mean visit duration, $T$

How busy would the EV charging facility be at this hour?
Charging Car Park Simulator – New Arrivals

UK EV Sales, 2017

‘Simple-Smart’ Charging Algorithm

In English:

- Minute-by-minute power flow control
- Cars arrive and plug in, no ‘user preferences’
- ‘Emptiest’ cars receive proportionally more power, subject to constraints (the grid, the converter, the EV itself and the current SoC)

In Maths:

1) Find Total Energy Requirement of car park

\[ \text{TER}_j = \sum_i n_j \cdot (1 - \text{SoC}_{ij}) \cdot C_i \]

2) Establish ‘Potential Charge Rate’ of each vehicle

\[ \text{PCR}_{ij} = \frac{(1 - \text{SoC}_{ij}) \cdot C_i}{\text{TER}_j} \cdot P_G \]

3) Charge Rate of each vehicle is the minimum of the PCR and any constraints

\[ \text{CR}_{ij} = \min \{ \text{PCR}_{ij}, P_{Bij}, P_C, P_{EV} \} \]

Case Study 1: Braehead Shopping Centre

• Large indoor shopping/entertainment complex
  ~10 km west of Glasgow, Scotland

• 6,500 car parking spaces

• Close to M8 motorway

• Potential location for large, transmission-connected EV charging car park
Case Study 1: Braehead Shopping Centre

Popular Times data

<table>
<thead>
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<th>Day</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
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<tr>
<td>Saturday</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunday</td>
<td>20 kW</td>
<td>50 kW</td>
<td>80 kW</td>
</tr>
</tbody>
</table>

Destination charging simulation

- 6,500 spaces
- Average time spent = 134 minutes

Expected demand profile for varying $P_G, P_C$
Braehead – Service Provision

• Assume that we can buy electricity at ~11 p/kWh\(^4\) and sell at 20 p/kWh (i.e. matching Ecotricity charge points)
• 300,000 kWh @ 9 p/kWh = £27k (Saturday)
• Saturday footfall ~ 21% of weekly footfall (from Popular Times data)
• \(\rightarrow\) expected revenues \(~£6.7m/\text{year}\)

Case Study 2: Glasgow Southside Supermarket

- 50 charging stations
- Variable grid connection and converter capacity

Distribution network assets – GIS data
Glasgow Southside Supermarket – Line Loading

Charging infrastructure connected to dedicated secondary substation straight to 11 kV network

11 kV feeder from primary to secondary substation (blue dot)
Comparison – Domestic Charging

- Car availability – UK Census
- Household size (no. residents)
- Accommodation type (terraced, flat etc.)
- Scottish Index of Multiple Deprivation (SIMD) decile (0-9)

![Graph showing time series data for EV penetration: 0%, 40%, 70%, and 100%](chart.png)
• Load flow simulation @ peak EV load (18:45)
• 70% domestic EV penetration and 1600/50 kW charging car park

Destination charging -> loading on HV feeder only

Domestic charging -> local voltage and loading issues
Interesting Questions

• How do these charging types interact with one another?
• Given a total ‘energy budget’, what’s the best way of providing an EV charging system for a fleet of EVs?
• What *should* the future EV charging system look like?
• Are there opportunities for ‘smart grid’ technologies to play a part in making this easier?
  – Demand side management (AKA ‘smart charging’)
  – Dynamic tariffs??
  – Distribution-level interconnection (RC switching, soft open points)
  – Storage (stationary, or the vehicle itself?)
Some Conclusions

• Destination charging could be a key part of EV charging infrastructure
• Charging load is likely to vary significantly based on where it is
• This method can be used to look at the temporal variation in demand between charging at different types of amenities
• We can then examine how the profiles of different kinds of charging (including rapid and domestic) interact with one another...
• ...and look at how we can best deal with it
Questions?

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