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Journey Models for Electric Road Freight Operations

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Introduction

- Number of HGVs lower than passenger cars but high emissions

96%	61% passenger vehicles	17% LDVs	22% HGVs

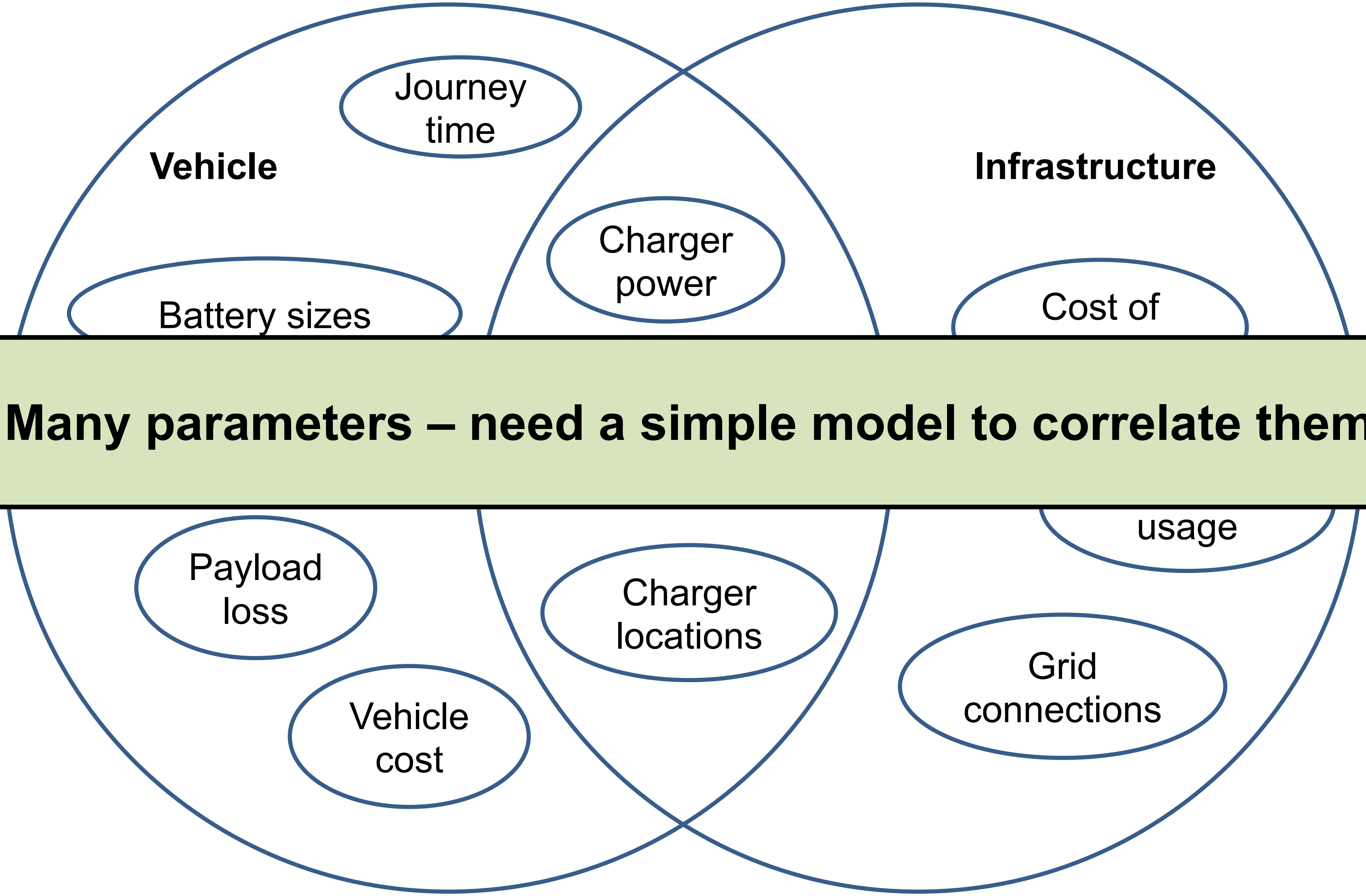
UK national CO_2 emissions — UK road transport CO_2 emissions

- Multiple decarbonisation solutions

Short-term solutions	Vehicle (tyres, aerodynamics, etc.) and operational improvements, biofuels, LNG, CNG…
Long-term solutions	FCEVs, BEVs, hybrids…

- Electrification – most promising but complex due to multiple parameters

Electrification Questions



Many parameters – need a simple model to correlate them

Charger Cost Breakeven

- Aim: To determine number of hours required for cost breakeven
- Capital cost:
  - Charger cost
  - Installation cost
  - Grid connection cost
    - depends on number of chargers at warehouse
- Income:
  - Electricity selling
    - depends on usage per day

$$n_h = \frac{C_{cap}\left[n_y \frac{r_i(1+r_i)^{n_i}}{(1+r_i)^{n_i}-1} + f\left(\frac{(1+r_z)^{n_y}-1}{r_z}\right)\right]}{\Delta r_e P_{max} n_d \left(\frac{(1+r_z)^{n_y}-1}{r_z}\right)}$$

Capital cost of charger (£)

Number of years for breakeven

Annual loan instalment fraction

Annual maintenance cost fraction

Number of hours of usage per day

Charger power (kW)

Number of days of use per year

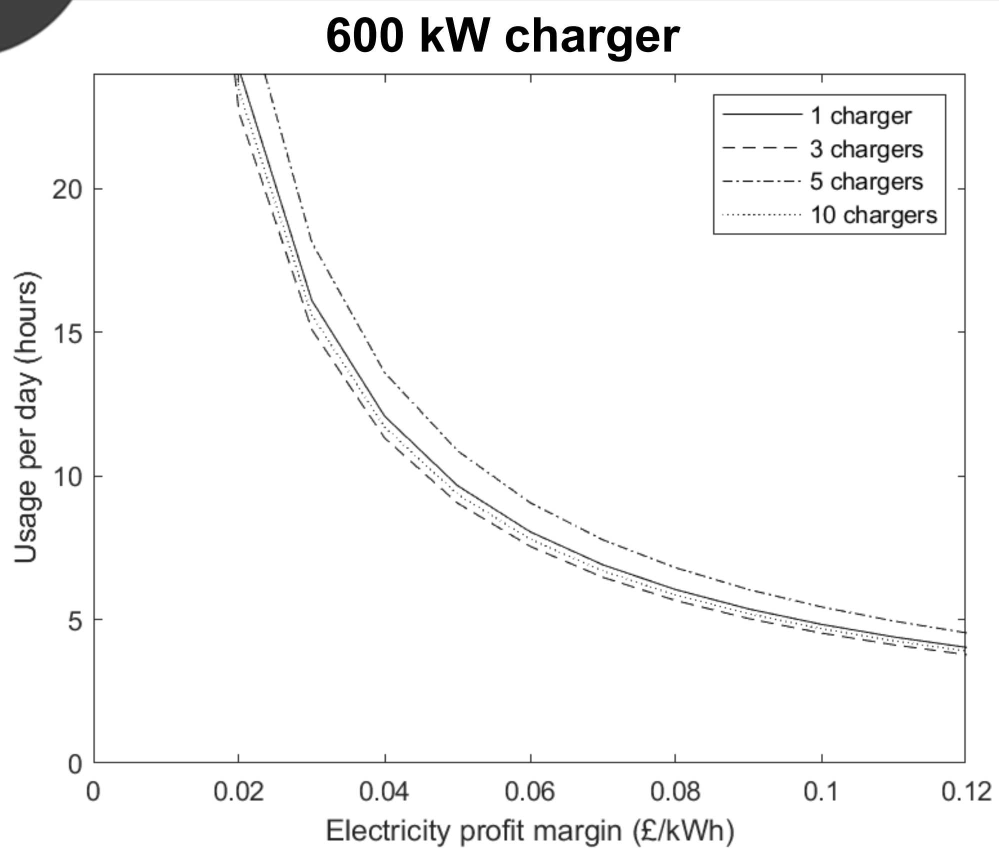
Sum of inflation terms over n_y years

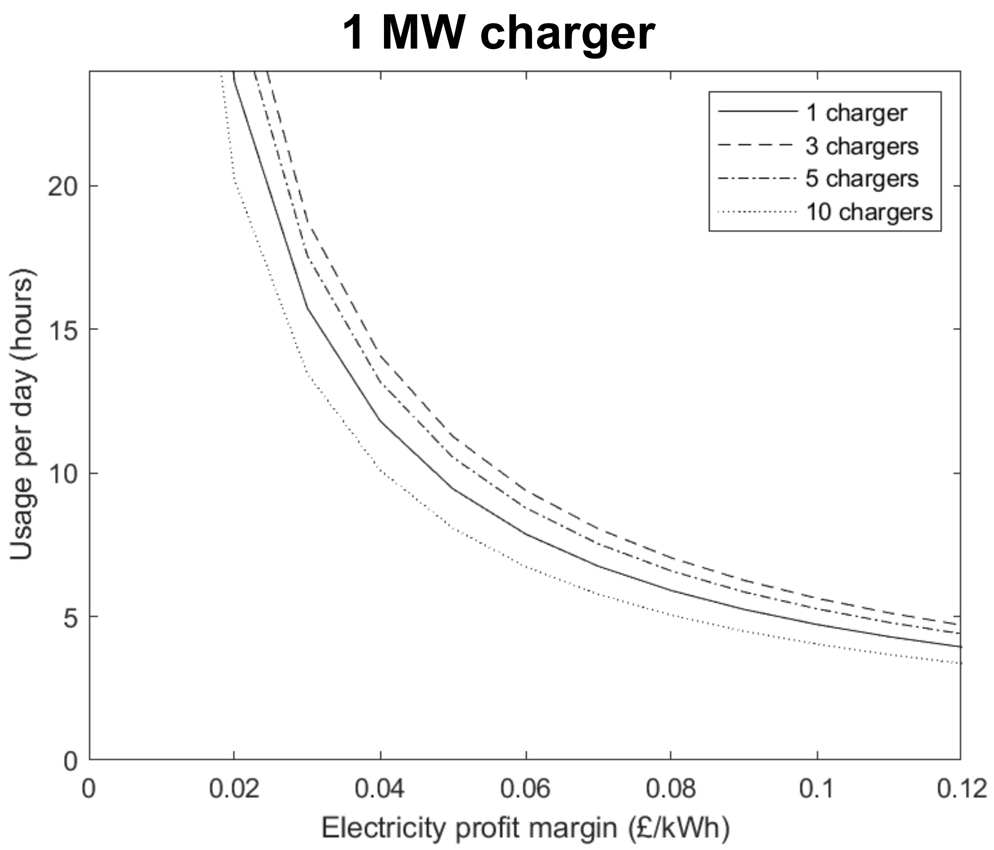
Electricity profit margin (£/kWh)

Ref: **Parth Deshpande et al., "Analysis of Fast Charging Arrangements for Electric Heavy Goods Vehicles", IEEE Intelligent Transportation Systems Conference (ITSC) 2023.**

Preprint: https://doi.org/10.36227/techrxiv.24290656.v1

Charger Cost Breakeven



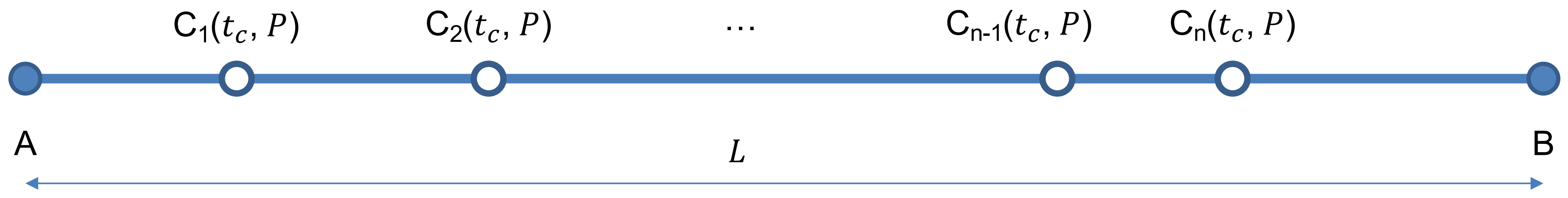


Stop time: 20 min.

Charger Type	Required minimum number of daily charge events			
	Δr_e= £0.04/kWh	Δr_e= £0.06/kWh	Δr_e= £0.08/kWh	Δr_e= £0.1/kWh
600 kW	41	27	20	16
1 MW	42	28	21	17

Simple Journey Model

- Aim: Model charging strategies for a simple A-to-B journey



Assumptions

Average speed: v_{avg} = 90 km/h – maintained by UK 44T HGVs for over 75% of the time

Average energy consumption: E = 1.7 kWh/km for a 40T loaded vehicle

Battery size required: ΔB = lowest battery dip / 80%

Overhead time at a charging stop: t_o= 10 minutes

Optimal Charging

- Aim: To find the Pareto optimal charging strategy for a journey
- Battery size:

$$\Delta B = \left(EL - \min\left(Pt_c, \frac{EL}{n_c + 1}\right) n_c\right) * \frac{1}{80\%}$$

Battery size required (kWh)

Average energy consumption (kWh/km)

Total journey length (km)

Charging duration (h)

Charger power (kW)

Number of charging stops

Maximum battery dip allowed

- Time factor:

$$\Delta T = \frac{(t_c + t_o) n_c}{t_{\mathrm{travel}}} * 100$$

Travel time increase (%)

Charging duration (min)

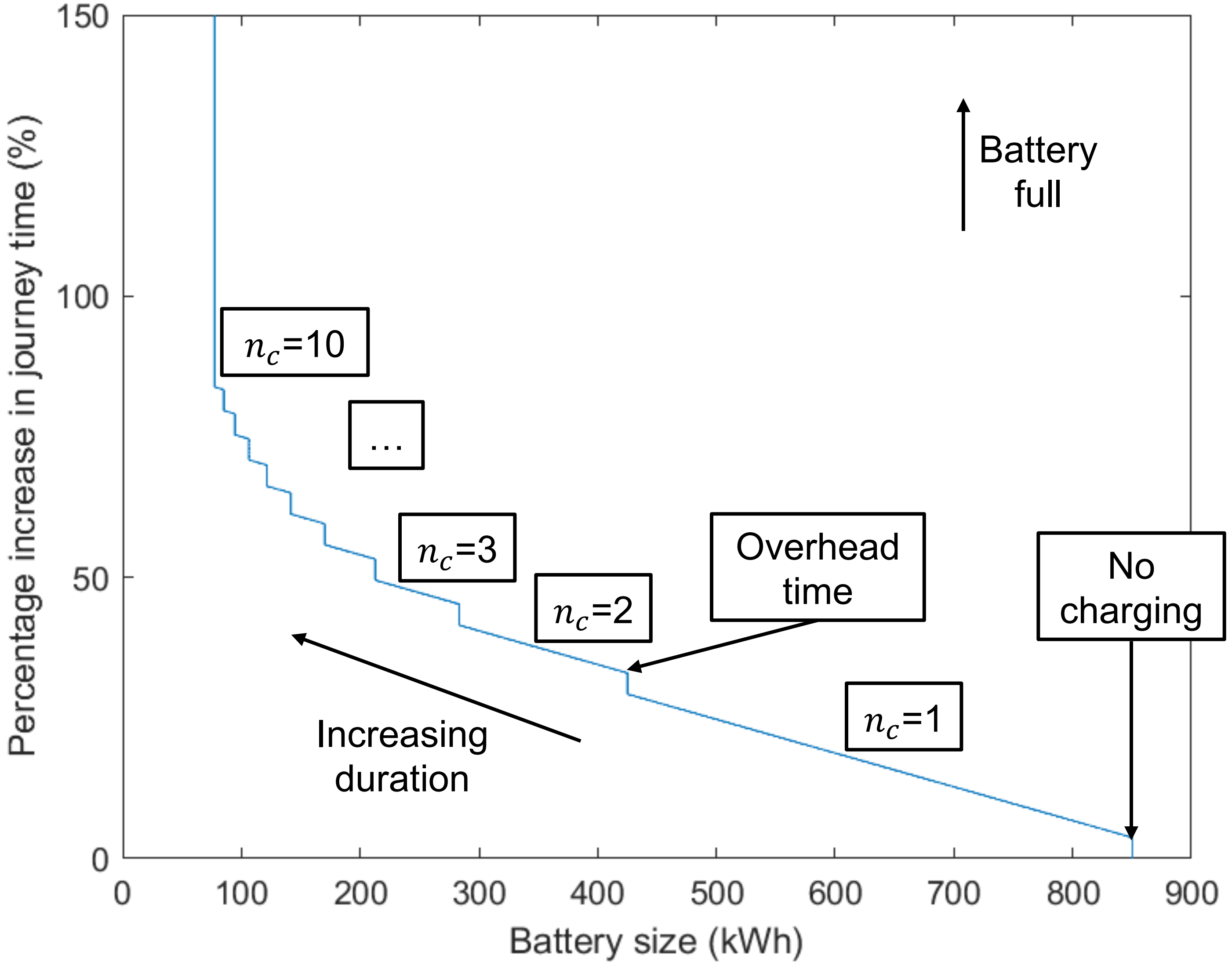
Overhead time per stop (min)

Base travel time (min)

Optimal Charging

- “Fundamental Diagram” of Electrified Logistics

- Journey length = 400 km
- 300 kW charging
- Up to 10 charging stops
- Overhead time per stop = 10 min



Optimal Charging

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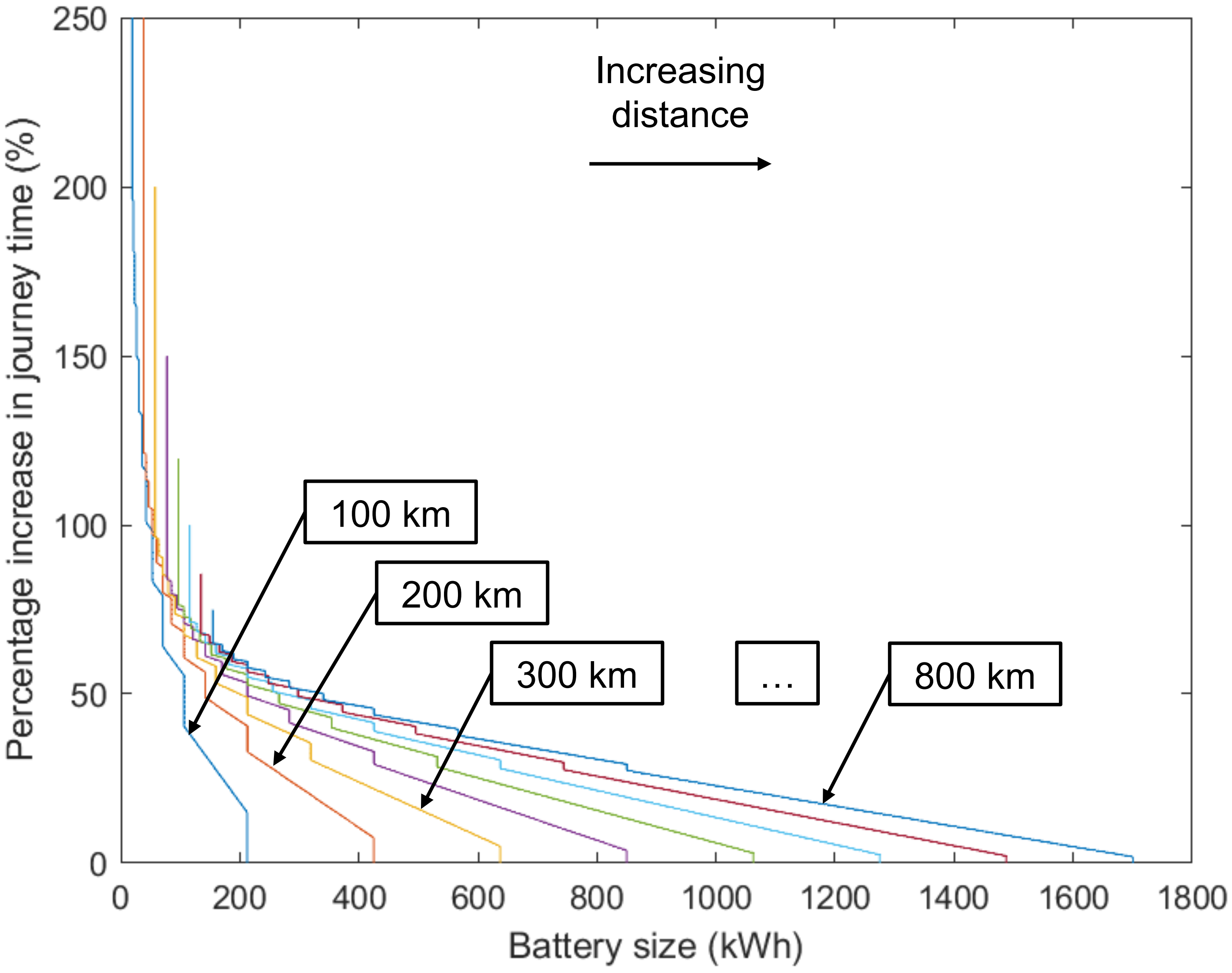

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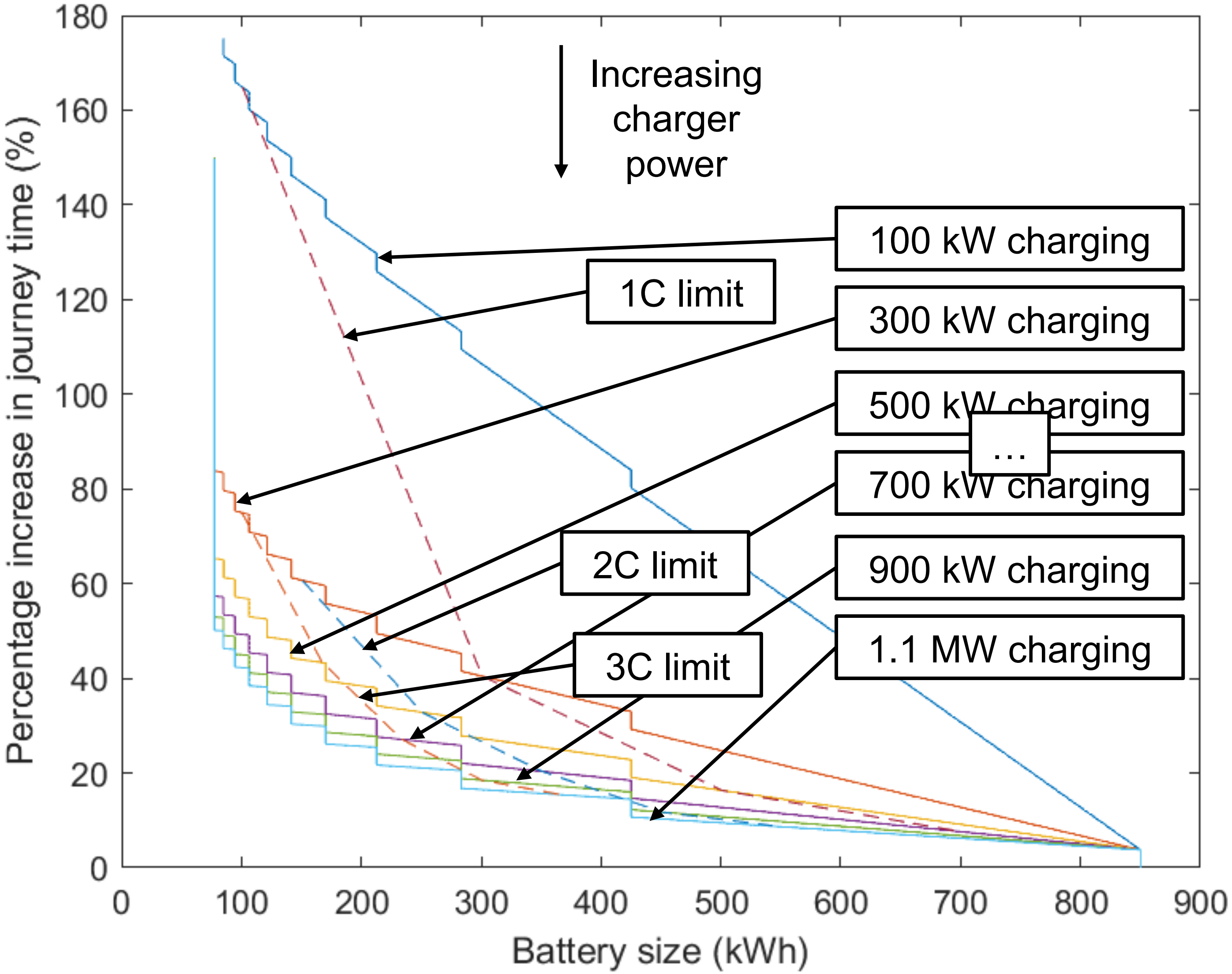
Charging Rate Limit

- Charging rate is measured in C
- 1C: 0-100% charging in 1 hour
- Current charging speeds are limited to **2C** for large batteries



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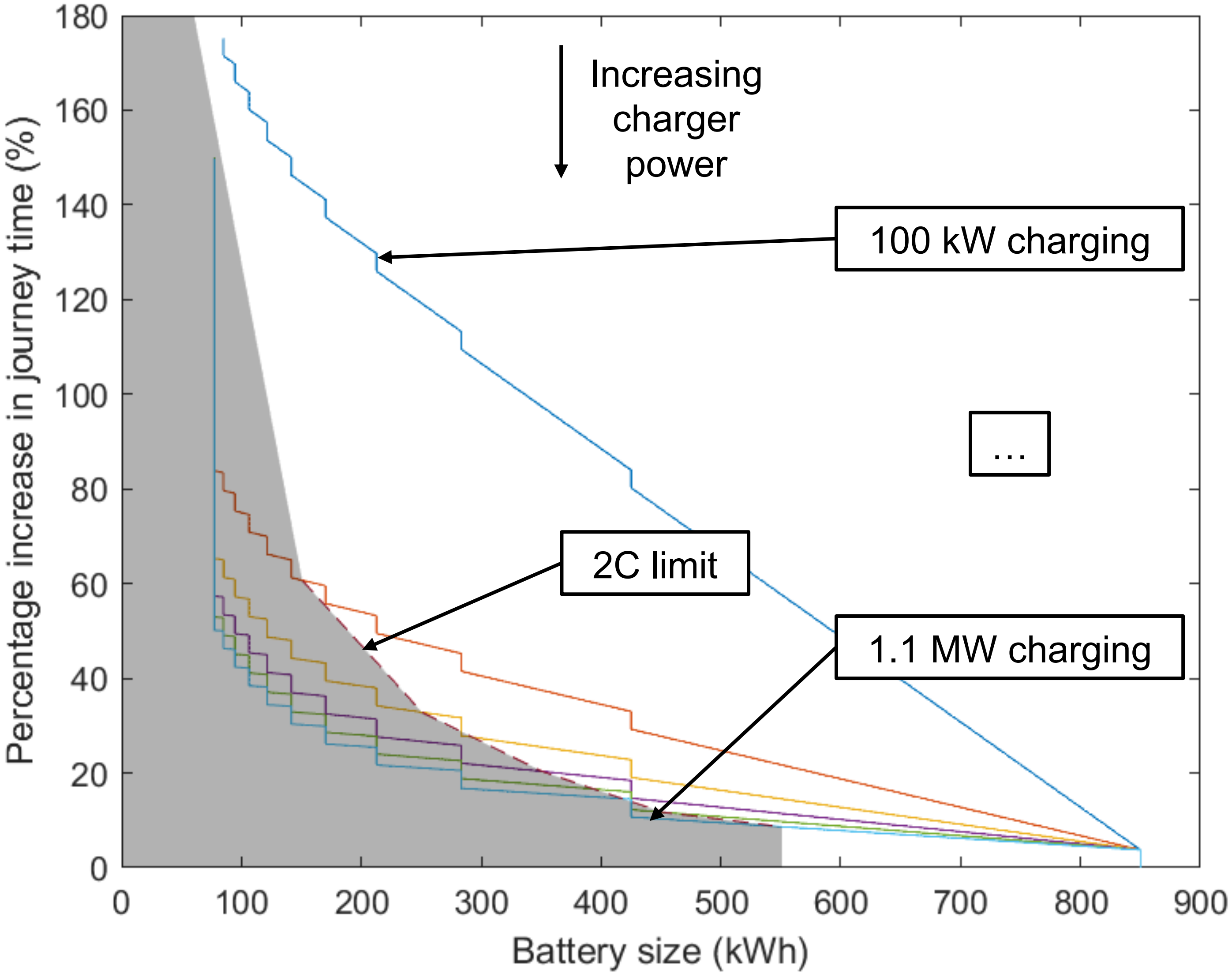
Applications

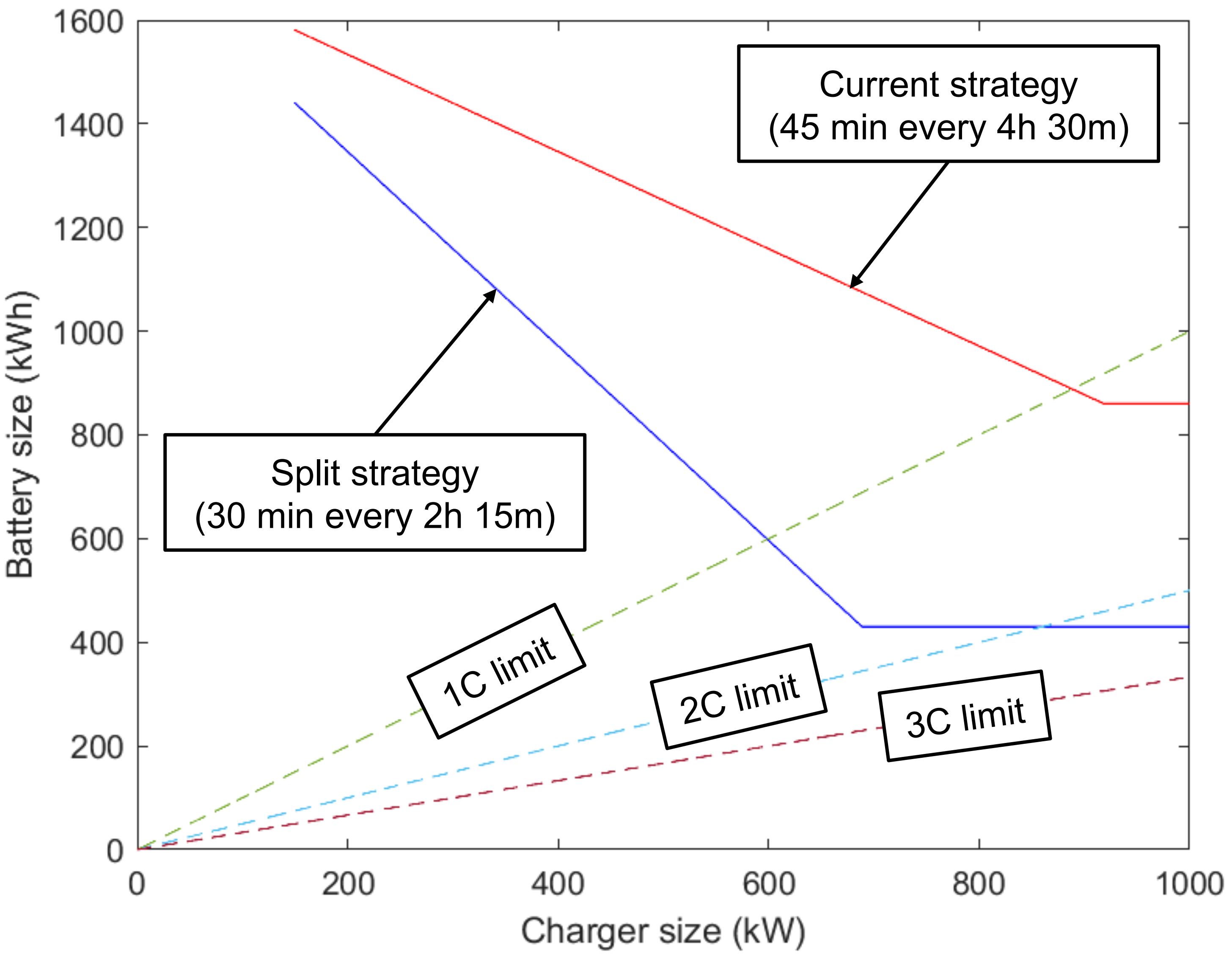
- Finding how many charging stops are needed
- Checking if current charging stops are optimal
- Comparing rest stop strategies…



Rest Stop Strategy Analysis

Case Study #1

- 810 km journey
- Assumed avg speed: 90 km/h
- Charging: 150 kW - 1 MW
- Current strategy:
  45 min after 4h 30m
  (1 stop over 810 km)
- Split strategy:
  30 min after 2h 15m
  (3 stops over 810 km)



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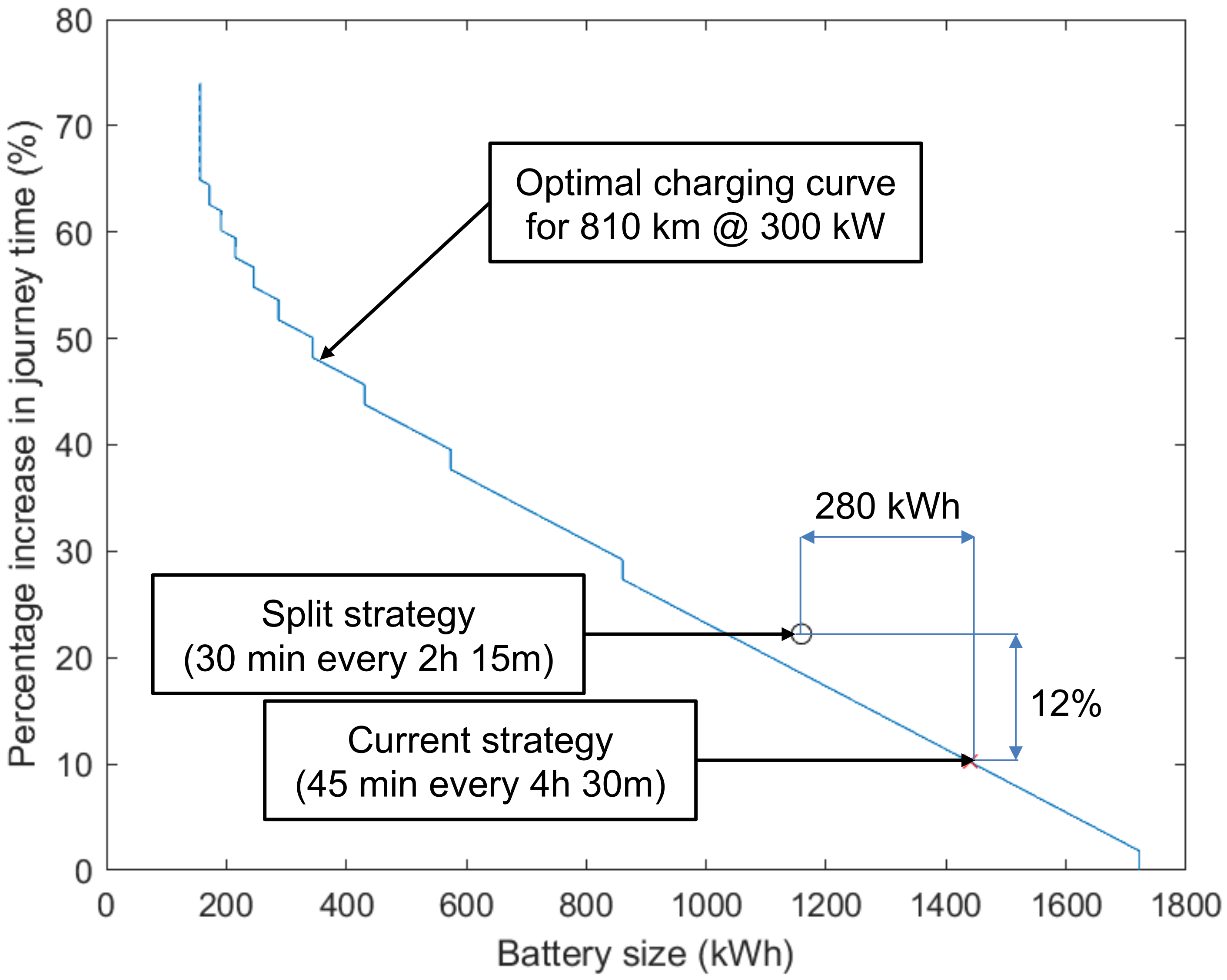
- **Additional time factor for split rest-stop strategy: 12%**



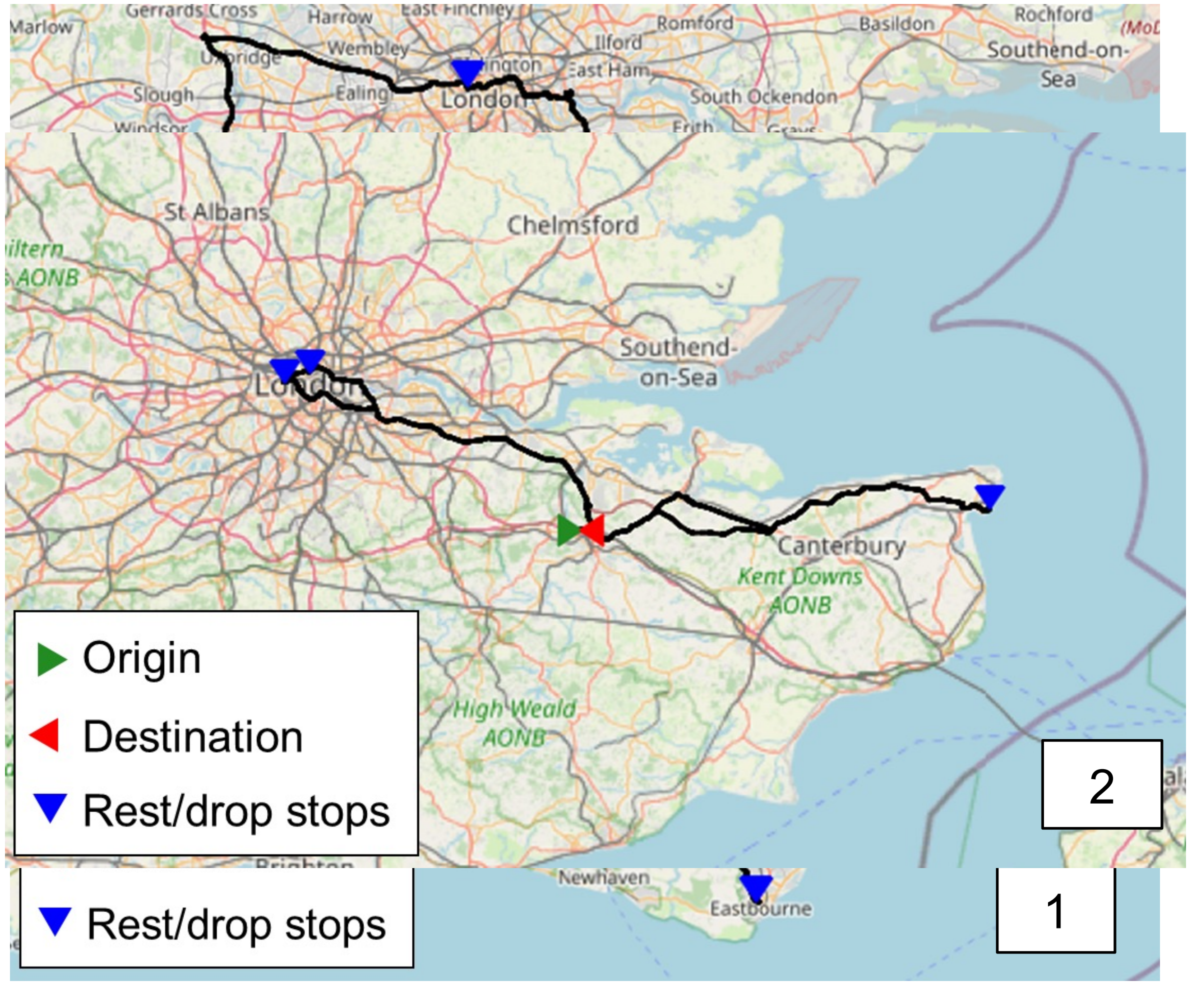
Supermarket Multi-Drop Journey Analysis

Case Study #2

- 2 journeys around 280 km
- Charging: 600 kW

Journey / Battery Size	DC 600 kW	DC+SCS 600 kW
(1) Aylesford - Eastbourne - Lewes - Marylebone - Aylesford	287	258
(2) Aylesford - Bloomsbury - Kensington Gardens - Ramsgate - Aylesford	316	206

DC: static charging at drop locations
SCS: Split rest stop strategy
(30 min stop every 02:15 hrs)



Ref: Christopher de Saxe et al., "An electric road system or big batteries: Implications for UK road freight", Transportation Engineering 2023, 100210.

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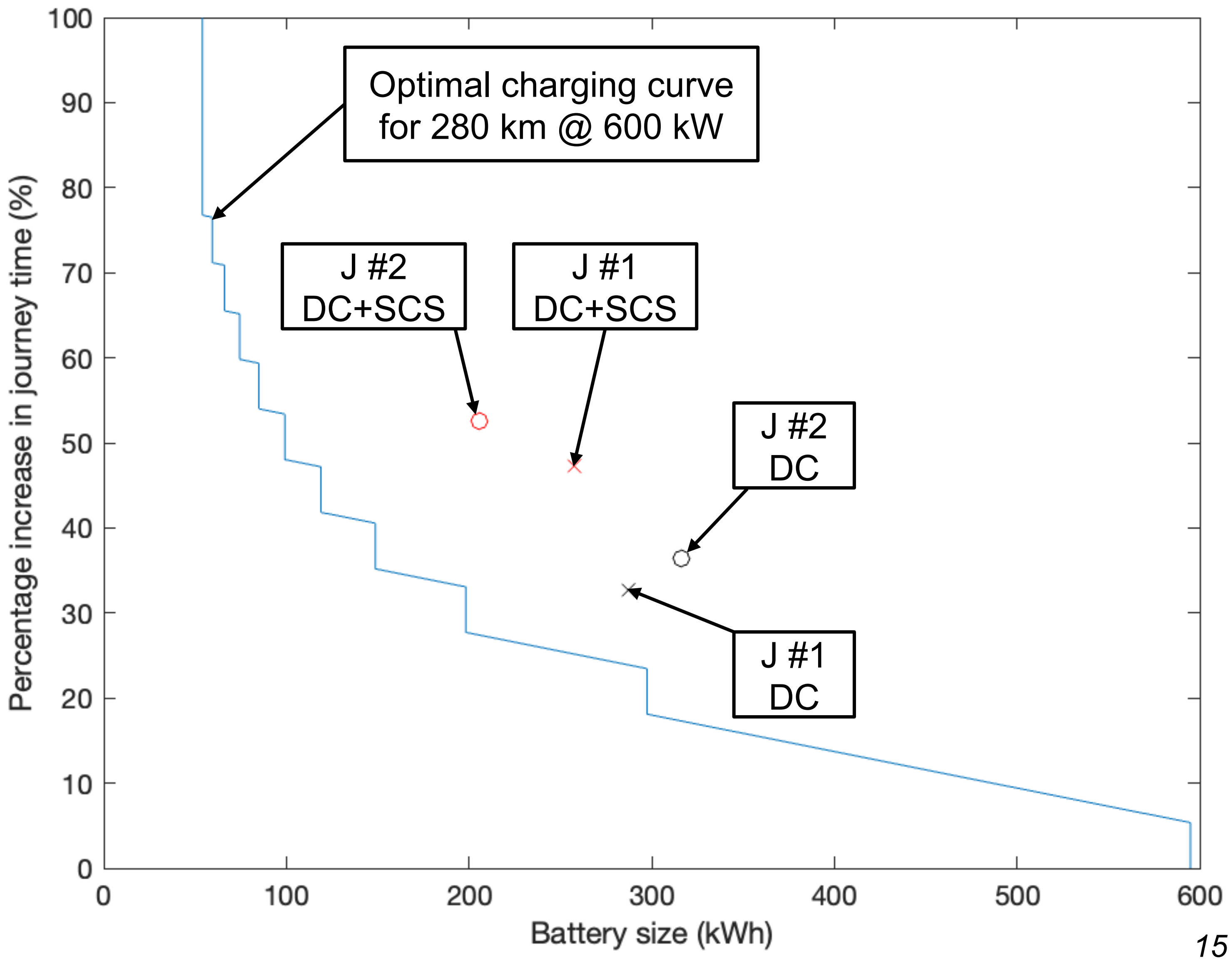

Summary

- Multiple parameters in electrification make it a complex problem to solve
- Cost breakeven for static chargers can be achieved with reasonable usage
- Fundamental diagrams for electrified logistics can help make operational decisions
- Examples of analyses include justifying split rest stops over longer infrequent ones
- This is just the starting point – many more complex variables can be added!

Future Work

- Analysing more journey variations and multiple linked journeys
- Incorporating adaptive charging rates (fast charging up to 80% followed by slow charging)
- Studying the impact of battery sizes on payload loss

Thank You!

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Appendix: Static Charger Pricing

Charger Unit Costs

Charger [kW]	Unit Price	Unit Installation (civils)
22	£2,000	£2,000
50	£15,000	£5,000
100	£60,000	£10,000
300	£150,000	£25,000
600	£250,000	£25,000
1000	£500,000	£25,000

Grid Connection Costs

Site Conn. Capacity [MW]	Cost [£]
0.05	£45,000
0.15	£75,000
0.3	£225,000
0.5	£450,000
1	£750,000
2	£1,500,000
3	£3,000,000
5	£4,500,000
8	£5,250,000
12	£6,000,000