

Time-optimised Route Planning for Electric Vehicles

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INTRODUCTION

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MOTIVATION

Motivation

Greedy Heuristic Algorithm

Optimal solution to a path

FUTURE WORK

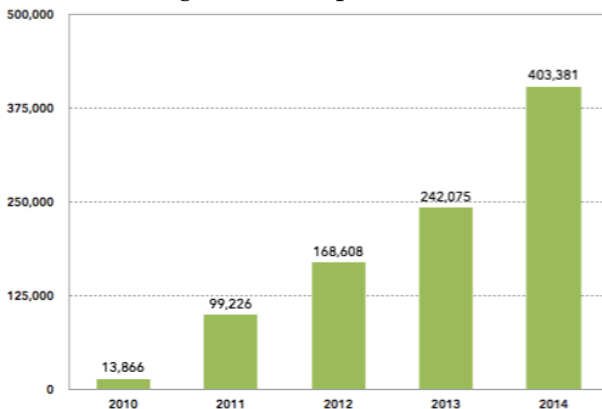
Future Work

Q & A

MOTIVATION

- Why is route planning for EVs an interesting problem?

Plug-in Vehicle production

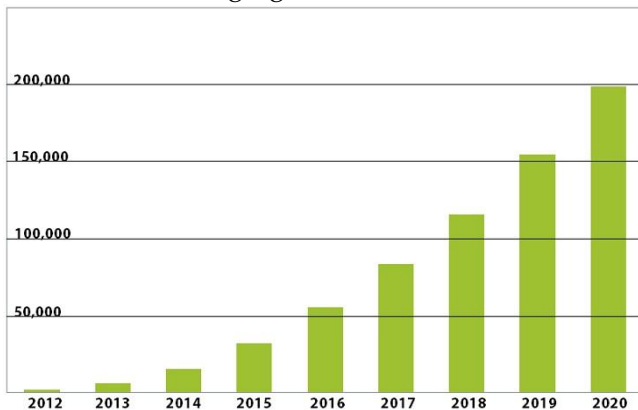


Credit: IHS automotive

MOTIVATION

- Why is route planning for EVs an interesting problem?

Fast-charging stations worldwide



Credit: IHS automotive

APPROXIMATION APPROACH

Idea:

- ▶ Drive using local optimal speed
- ▶ Use time as weight
- ▶ Solve as a CSPP using Dijkstra

The assumption here is that the shortest path, according to $\frac{\text{distance}}{\text{speed}}$, is the fastest in most cases

How to find the local optimal speed in any given situation?
Compute the time spent doing the following:

1. Drive
2. Drive and charge

Then, pick the fastest

We will now consider how to compute the two

DRIVING

The optimal speed when passing edge $e = (u, v)$ can be found by solving this equation for v :

$$B_{cur} - D(e) \times R_{CO}(v) = 0$$

Resulting in v_{opt1} , the time spent passing this edge is then: $\frac{D(e)}{v_{opt1}}$
Might not be possible!

DRIVING AND CHARGING

Charging is more complicated.. Instead one wants to:

1. Charge using the previously best charging station, which was not fully charged at
2. Compute the time to pass edge e
3. Repeat step 1-2 while it results in a faster passing of e

Thus we are able to utilise previously passed charging stations, to charge even more

Remember that we only charge exactly enough to pass every edge!

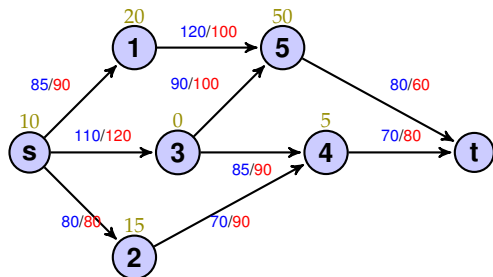
Consequences of this approach:

- ▶ Charging stations are not prioritized
- ▶ Choices might get the vehicle “stuck”
- ▶ ...

How do we fix this?

- ▶ Prioritize nodes with charging stations and lowest time
- ▶ Thus we are able to solve more graphs
- ▶ Not ideal solution

EXAMPLE



Edge weights:

- ▶ distance (km)
- ▶ speed limit(km/hr)

Node weights:

- ▶ charging speed (kW)

Paths:

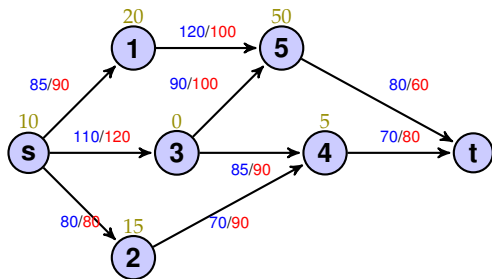
$\langle s, 1, 5, t \rangle$: 285km, 3.5hr

$\langle s, 3, 4, t \rangle$: 265km, 2.7hr

$\langle s, 3, 5, t \rangle$: 280km, 3.2hr

$\langle s, 2, 4, t \rangle$: 220km, 2.7hr

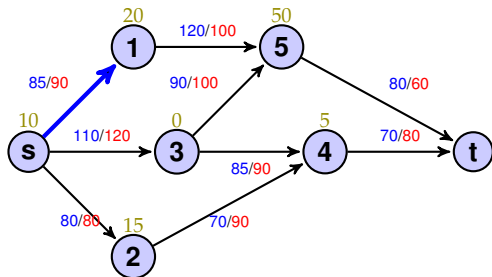
EXAMPLE


 $Q = \{s\}$

Best: s

	π	time	bat
s		0	50
1			
2			
3			
4			
5			
t			

EXAMPLE

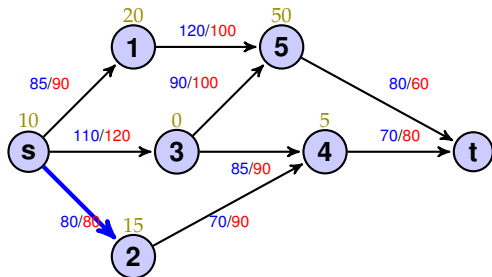


Driving: 90km/hr: 0.94 hr

Drive and charge: Same

	π	time	bat
s		0	50
1	s	0.9	27.1
2			
3			
4			
5			
t			

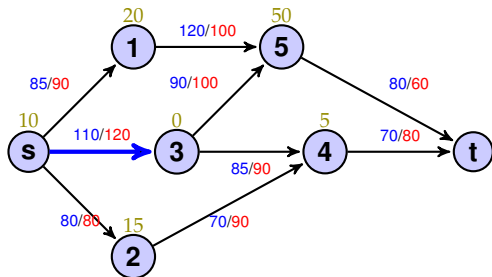
EXAMPLE



Driving: 80km/hr: 1hr
 Drive and charge: Same

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3			
4			
5			
t			

EXAMPLE

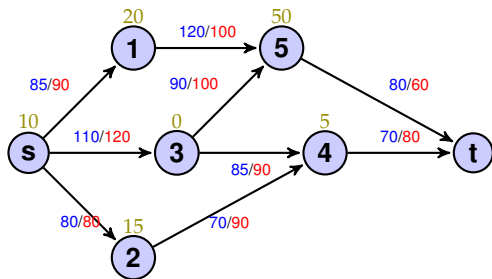


Driving: 120km/hr: 0.92hr

Drive and charge: Same

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5			
t			

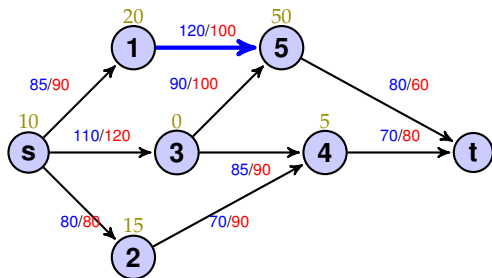
EXAMPLE


 $Q = \{1, 3, 2\}$

Best: 1

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5			
t			

EXAMPLE

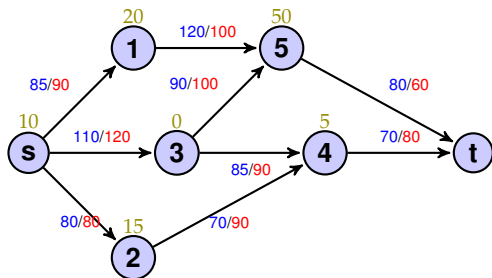


Driving: 71.1km/hr: 1.7 hr

Drive and charge: 88.1km/hr: 1.6 hr

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

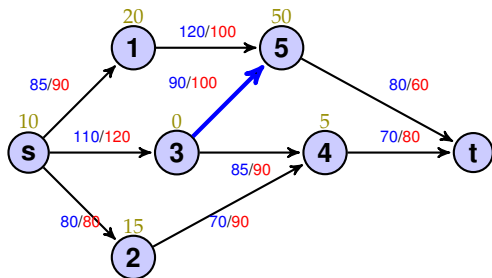
EXAMPLE


 $Q = \{3, 2, 5\}$

Best: 3

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

EXAMPLE

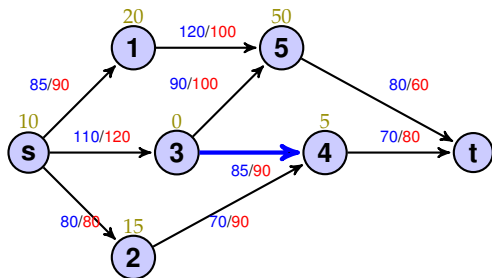


Driving: Not possible!

Drive and charge: Not possible!

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

EXAMPLE

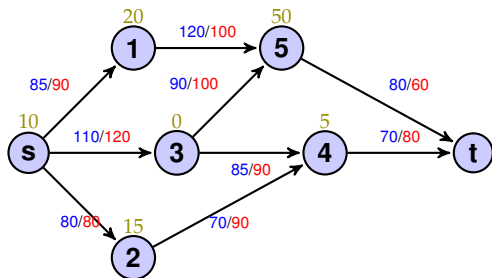


Driving: Not possible

Drive and charge: Not possible!

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

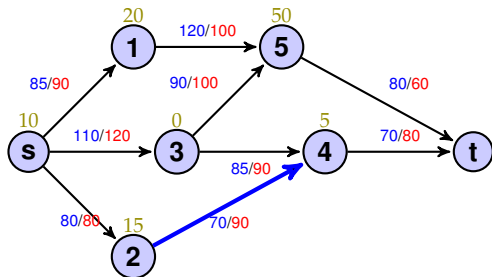
EXAMPLE


 $Q = \{2, 5\}$

Best: 2

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

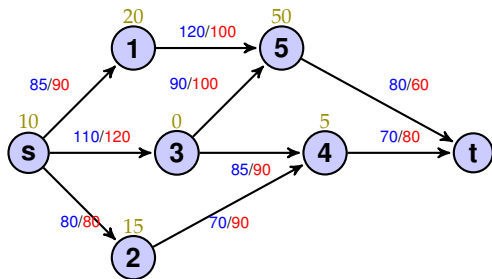
EXAMPLE



Driving: 90km/hr: 0.8hr
 Drive and charge: Same

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t			

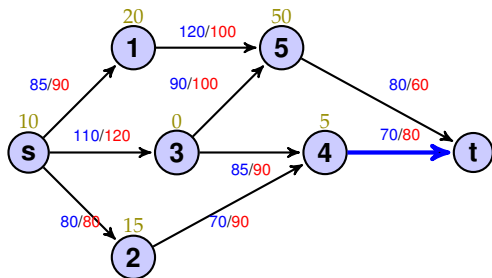
EXAMPLE


 $Q = \{5, 4\}$

Best: 4

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t			

EXAMPLE



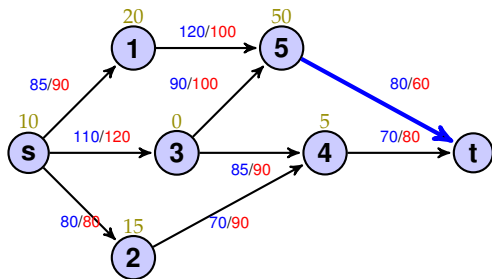
Driving: Not possible

Drive and charge: 58.6km/hr:

1.7hr

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t	4	3.5	0

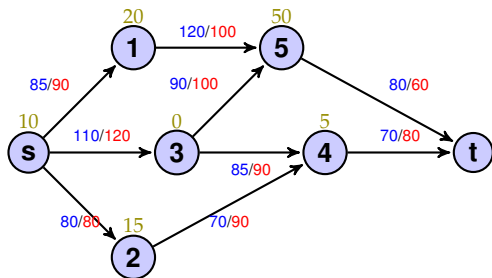
EXAMPLE


 $Q = \{5\}$

Best: 5

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t	4	3.5	0

EXAMPLE

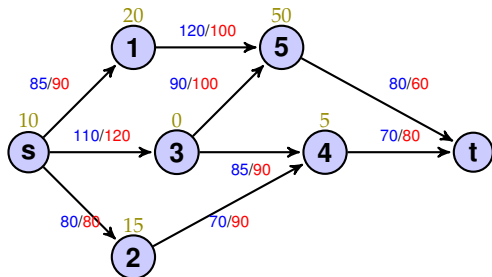


Driving: Not possible

Drive and charge: 120km/hr:
1.2hr

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t	4	3.5	0

EXAMPLE

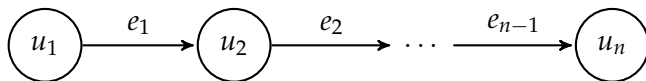


Shortest path was fastest!

	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t	4	3.5	0

PHYSICAL SYSTEM

Modeling the physical system, of an EV and a path.



► Path

- + Charging stations, with charging rate ($R_{CH}(u_i)$)
- + Road segments, with speed limit ($v_{min}(e_i), v_{max}(e_i)$) and distance ($D(e_i)$)

► EV

- + Driving consumes energy accordingly to the speed of the EV, defined by: ($R_{CO}(e_i)$)
- + Further two constants from the EV are important to model, namely, battery capacity (B_{max}) and initial battery (B_{cur})

OPTIMISATION PROBLEM

Formulating a optimisation problem, which when solved will yield a optimal solution.

- ▶ Objective: Move from u_1 to u_n using minimum time .
 - + Time can be used driving or charging.
 - min: $\sum_{i=1}^{n-1} \left(\frac{D(e_i)}{v_{e_i}} + CT_{u_i} \right)$
- ▶ Physical constraints:
 - + Each edge must be driven at a speed within the speed limit:
 - $\forall i \in 1 \dots n-1 : v_{min}(e_i) \leq v_{e_i} \leq v_{max}(e_i)$
 - + Time can only be positive.
 - $\forall i \in 1 \dots n : 0 \leq CT_{u_i}$
 - + The energy is the battery must always be between 0 and B_{max}

BATTERY CONSTRAINT

The battery constraint of the optimisation problem can be split into two parts

- ▶ No road segment can be passed without having the required energy
- ▶ No overcharging at any charging station.

Energy can be..

- ▶ Spend: $\forall_{i \in 1 \dots n-1} : ES(e_i) = D(e_i) \times R_{CO}(v_{e_i})$
- ▶ Acquired: $\forall_{i \in 1 \dots n} : EA(u_i) = R_{CH}(u_i) \times CT_{u_i}$
- ▶ Already in the battery: B_{cur}

LINEAR PROGRAMMING

NP-complete problem.

Linearization and linear programming for approximate solution.

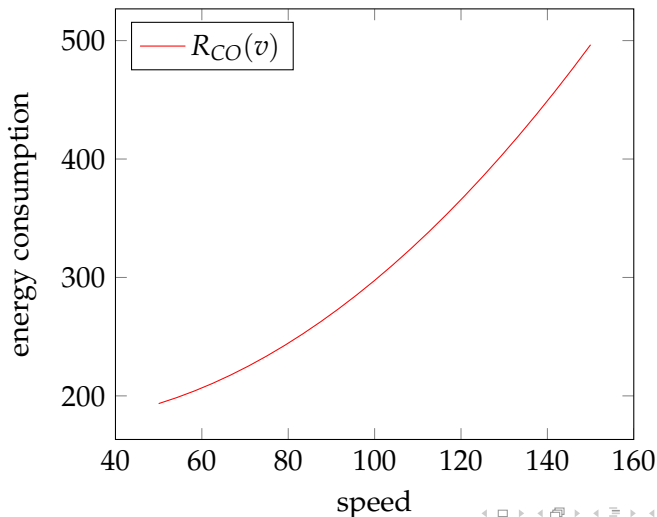
Two functions of the optimisation problem are non linear functions.

- ▶ Consumption rate ($R_{CO}(v_{e_i})$)
- ▶ Driving time ($\frac{D(e_i)}{v_{e_i}}$)

LINEARIZATION EXAMPLE

Function for energy consumption before linearization.

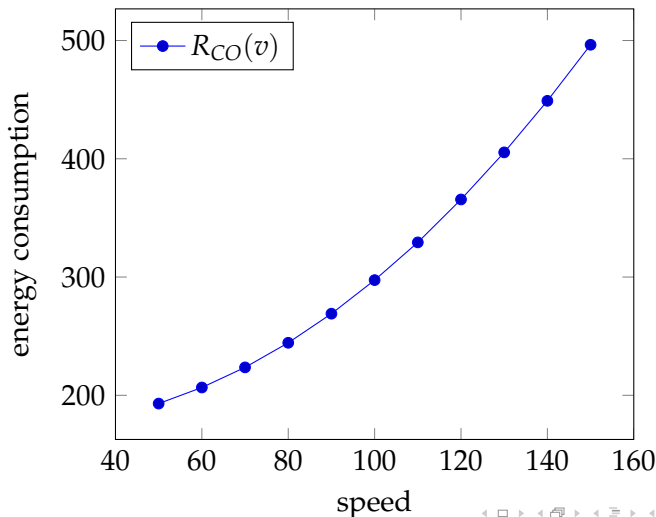
$$R_{CO}(v) = 0.019 * x^2 - 0.770 * x + 184.4$$



LINEARIZATION EXAMPLE

Function for energy consumption after linearization.

$$R_{CO}(v) = 0.019 * x^2 - 0.770 * x + 184.4$$



LINEARIZATION EXAMPLE

- ▶ For all linear function their slope and the y-intercept is precomputed.
- ▶ For every edge in the path exactly one line segment needs to be chosen. Thus a binary matrix is introduced of size $n \times m$, where n = edges in the path and m = linear pieces of each line.

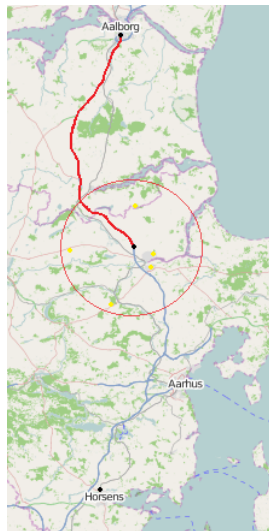
EXPERIMENTS

- ▶ Why experiments?
- ▶ Map data (Open Street Maps)
- ▶ Conversion to road network

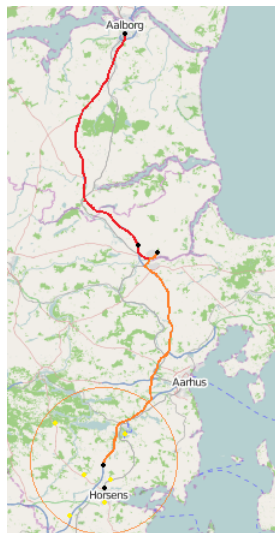
EXPERIMENTS: THE SETUP

- ▶ Battery capacity: 50 kWh
- ▶ Consumption rate: $0,019v^2 - 0,77v + 184,4$ wH/km
- ▶ Driving distance: 300 km
- ▶ Charge rates: 10-100 kW
- ▶ Charge station density: 20 km

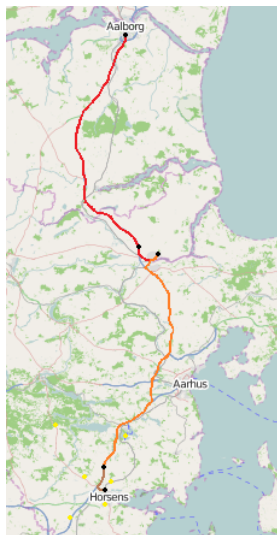
EXPERIMENTS: THE NAIVE ALGORITHM



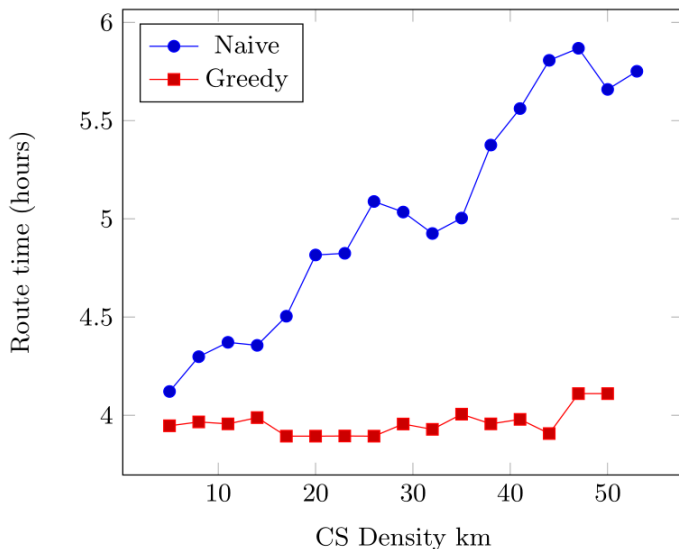
EXPERIMENTS: THE NAIVE ALGORITHM



EXPERIMENTS: THE NAIVE ALGORITHM



EXPERIMENTS: CHARGE STATION DENSITY



EXPERIMENTS: CHARGE STATION DENSITY

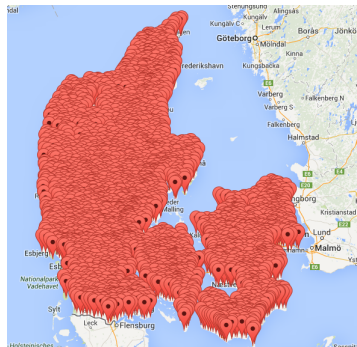


Figure : 5 km between Charge Stations

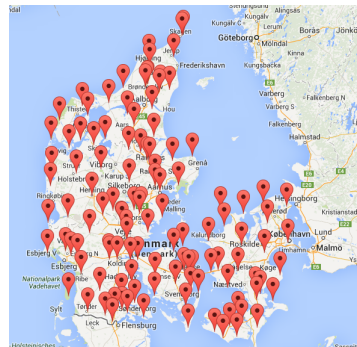


Figure : 30 km between Charge Stations

EXPERIMENTS: CHARGE STATION DENSITY

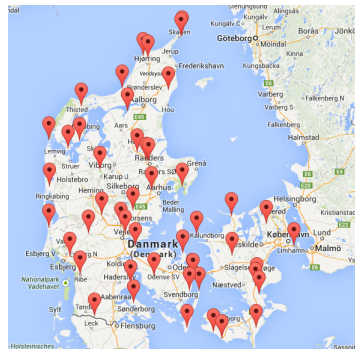


Figure : 50 km between Charge Stations

EXPERIMENTS: QUALITY ASSESSMENT

- ▶ Standard setup
- ▶ Average from 8 experiments

Results:

Naive	7,461
LP	5,684

Greedy	5,238
LP	5,228

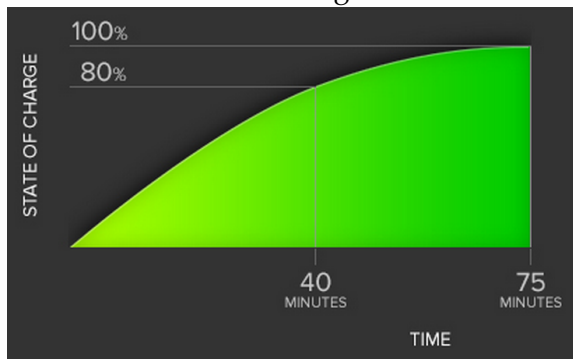
CONCLUSION

- ▶ 0,1% worse than LP
- ▶ Not influenced much by CS density
- ▶ Too slow in practice
- ▶ Increasingly important
 - ▶ Charging time significant
 - ▶ Increasing EV sales

FUTURE WORK

- ▶ Variable Charge rates

Model S Charge Rate



Credit: Tesla Motors, inc.

FUTURE WORK

- ▶ Variable Charge rates
- ▶ Better heuristic choices
- ▶ Speed-up techniques
- ▶ Branch & Bound or some other pruning method

Q & A TIME