Time-optimised Route Planning for Electric Vehicles

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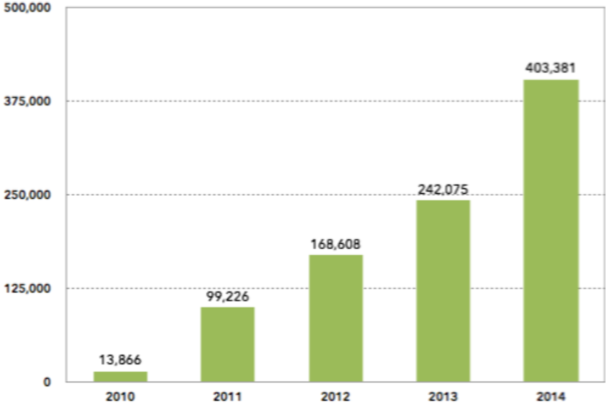
INTRODUCTION

MOTIVATION

- Why is route planning for EVs an interesting problem?

Plug-in Vehicle production

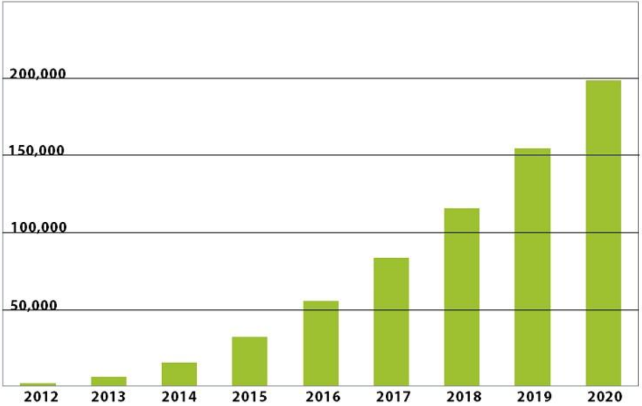


Credit: IHS automotive

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 $\frac{distance}{speed}$, 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!

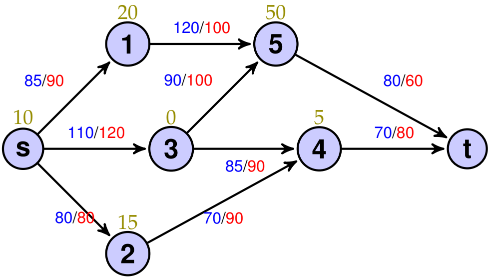
Consequences of this approach:

- 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)

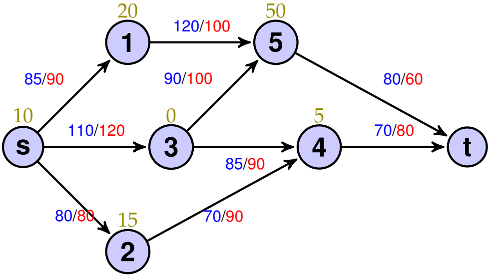
Node weights:

- 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

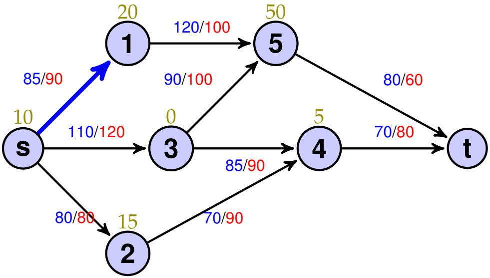


	π	time	bat
s		0	50
1			
2			
3			
4			
5			
t			

$Q = \{s\}$

Best: s

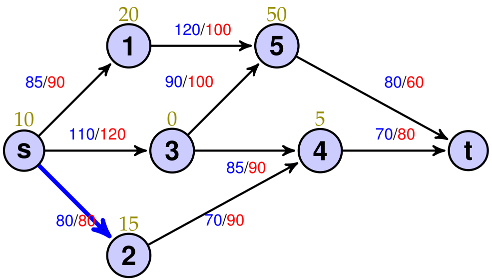
EXAMPLE



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			

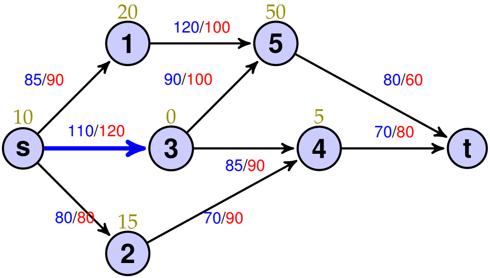
EXAMPLE



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

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

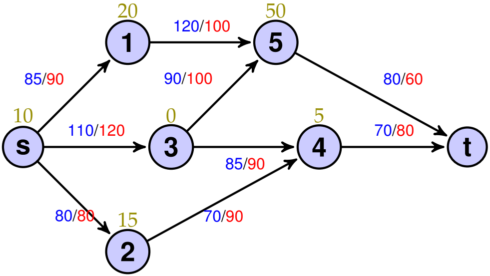
EXAMPLE



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

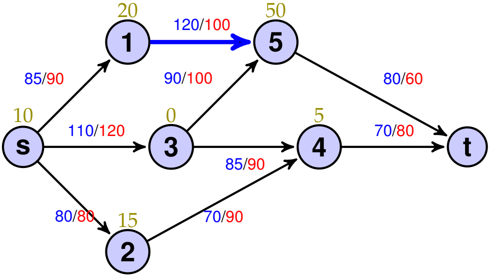


	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5			
t			

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

Best: 1

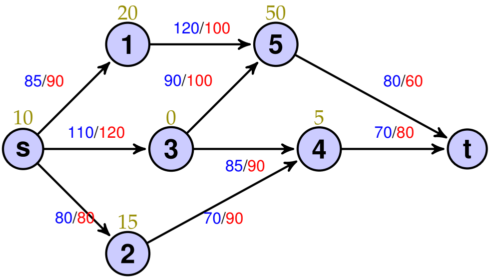
EXAMPLE



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

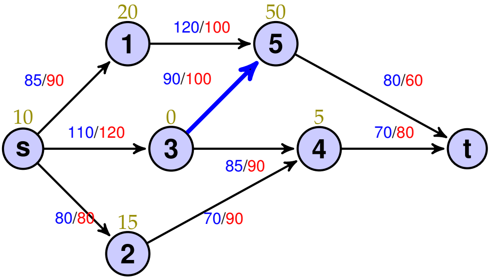


	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

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

Best: 3

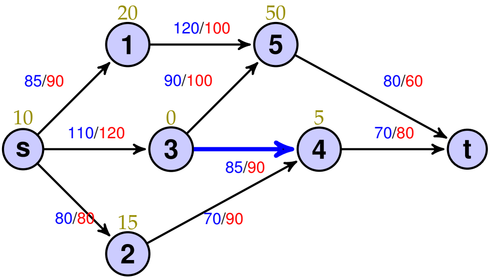
EXAMPLE



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			

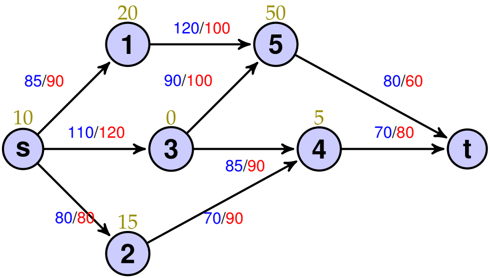
EXAMPLE



	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			

Driving: Not possible
Drive and charge: Not possible!

EXAMPLE

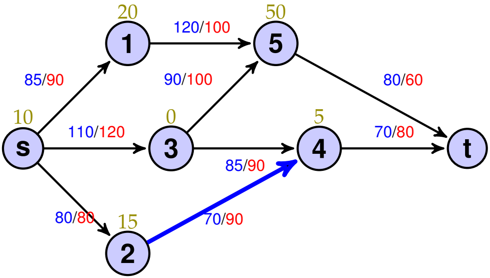


	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4			
5	1	2.5	0
t			

$Q = \{2, 5\}$

Best: 2

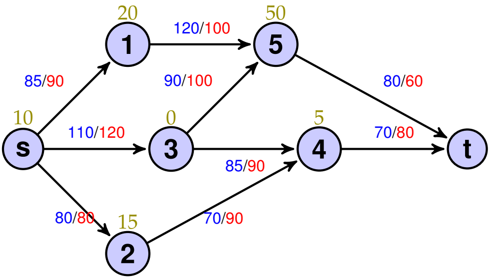
EXAMPLE



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

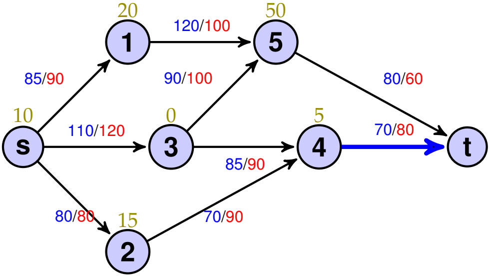


$Q = \{5, 4\}$

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			

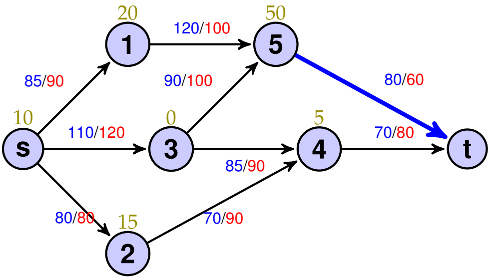
EXAMPLE



	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

Driving: Not possible
Drive and charge: 58.6km/hr: 1.7hr

EXAMPLE

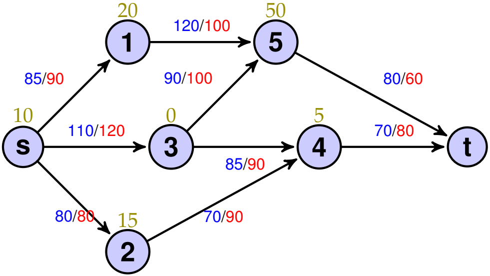


	π	time	bat
s		0	50
1	s	0.9	27.1
2	s	1	30.4
3	s	0.9	9.8
4	2	1.8	11.6
5	1	2.5	0
t	4	3.5	0

$Q = \{5\}$

Best: 5

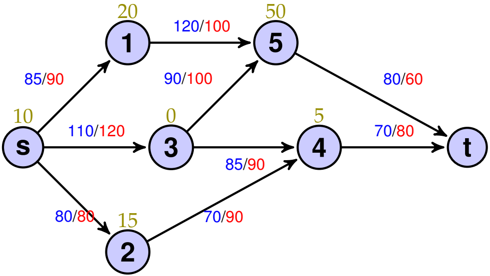
EXAMPLE



	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

Driving: Not possible
Drive and charge: 120km/hr: 1.2hr

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.

$$u_1 \xrightarrow{e_1} u_2 \xrightarrow{e_2} \cdots \xrightarrow{e_{n-1}} u_n$$

- 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 optimization 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:
    - $\forall_{i \in 1 \ldots n-1} : \; v_{min}(e_i) \leq v_{e_i} \leq v_{max}(e_i)$
  - Time can only be positive.
    - $\forall_{i \in 1 \ldots n} : \; 0 \leq CT_{u_i}$
  - The energy is the battery must alway be between 0 and B_{max}

BATTERY CONSTRAINT

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

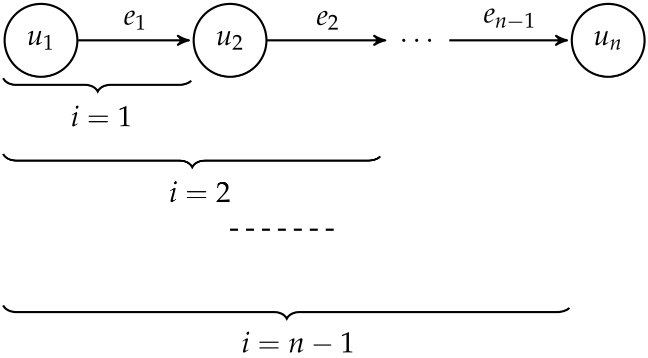
- No road segment can be passed without having the required energy
- No overcharging at any charging station.

Energy can be..

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

BATTERY CONSTRAINT

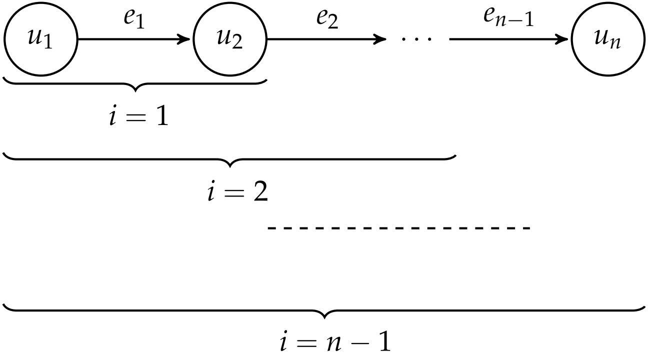
No road segment can be passed without having the required energy



- $\forall_{i \in 1 \ldots n-1} : \; 0 \leq B_{cur} + \sum_{j=1}^{i} EA(u_j) - \sum_{j=1}^{i} ES(e_j) \leq B_{max}$

BATTERY CONSTRAINT

No overcharging at any charging station.



- $\forall_{i \in 1 \ldots n-1} : \; 0 \leq B_{cur} + \sum_{j=1}^{i+1} EA(u_j) - \sum_{j=1}^{i} ES(e_j) \leq B_{max}$

LINEAR PROGRAMMING

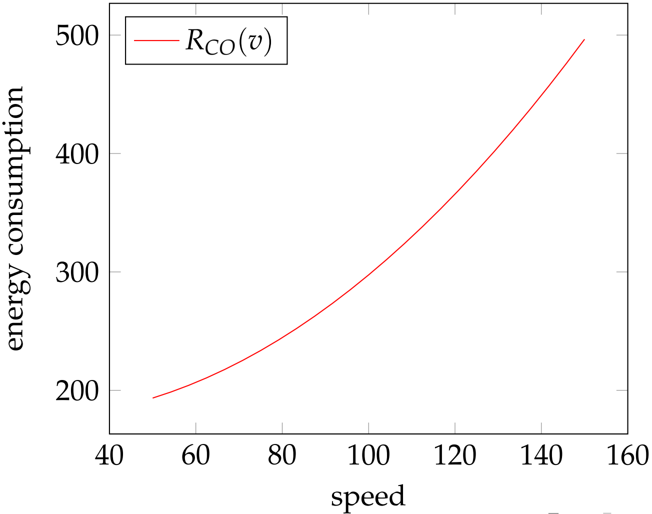
NP-complete problem.
Linearization and linear programming for approximate solution.
Two functions of the optimization problem are non linear functions.

- 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

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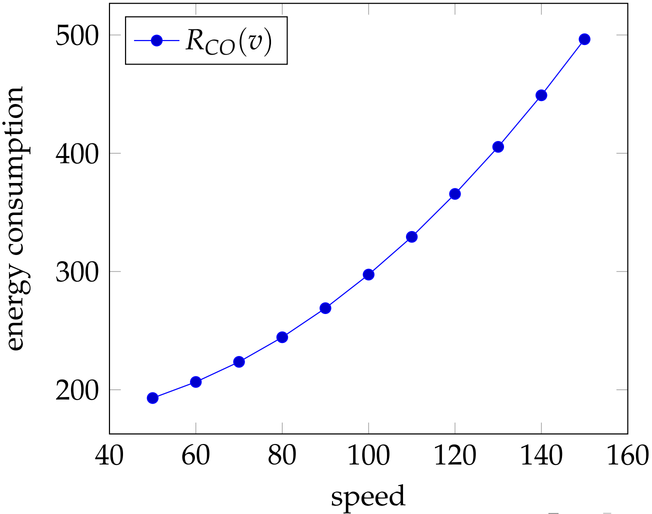


LINEARIZATION EXAMPLE

- 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 i introduced of size $n \times m$, where $n =$edges in the path and $m =$linear pieces of each line.

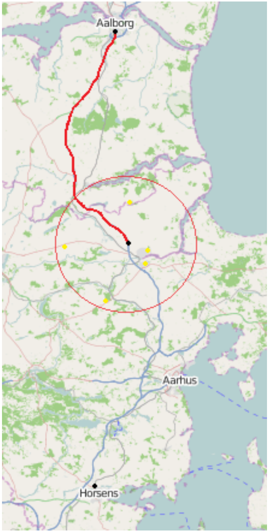
EXPERIMENTS

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

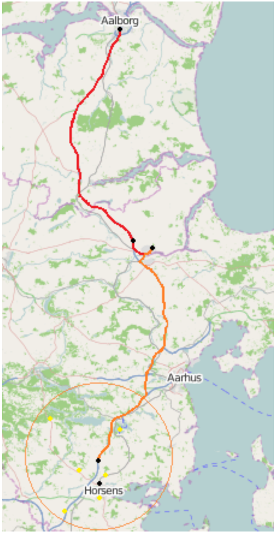
EXPERIMENTS: THE SETUP

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

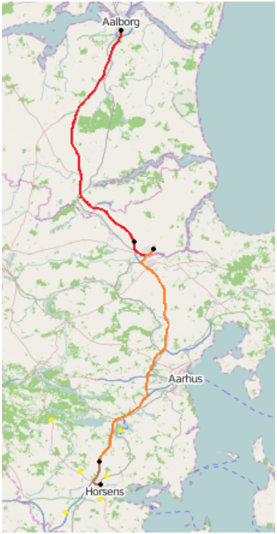
EXPERIMENTS: THE NAIVE ALGORITHM



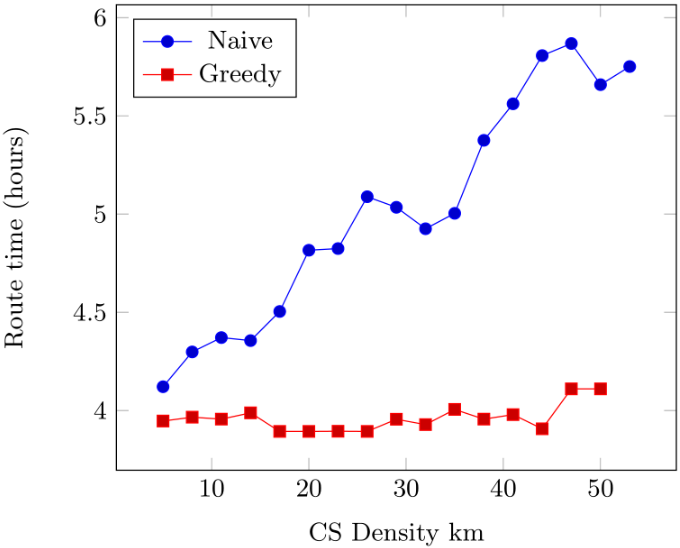
EXPERIMENTS: THE NAIVE ALGORITHM



EXPERIMENTS: THE NAIVE ALGORITHM



EXPERIMENTS: CHARGE STATION DENSITY



EXPERIMENTS: CHARGE STATION DENSITY

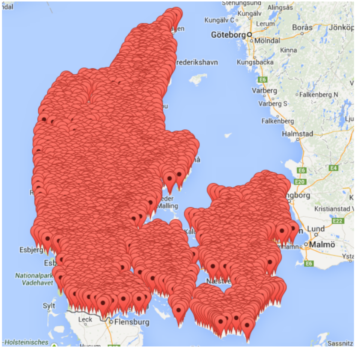


Figure : 5 km between Charge Stations

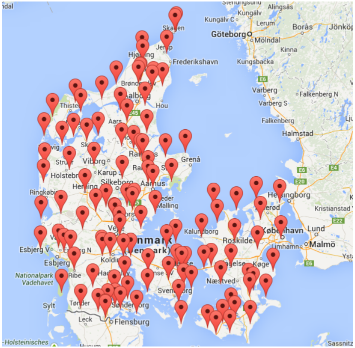


Figure : 30 km between Charge Stations

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

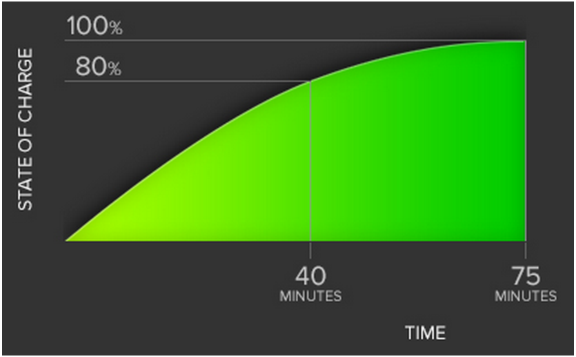
CONCLUSION

- $0,1\%$ 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