Time-optimised Route Planning for Electric Vehicles

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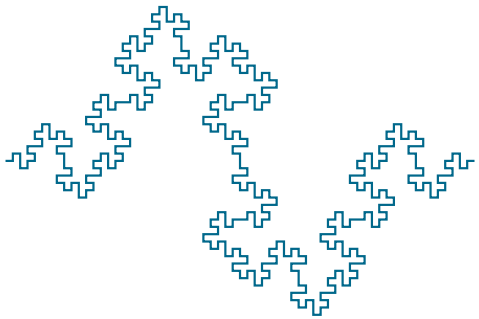
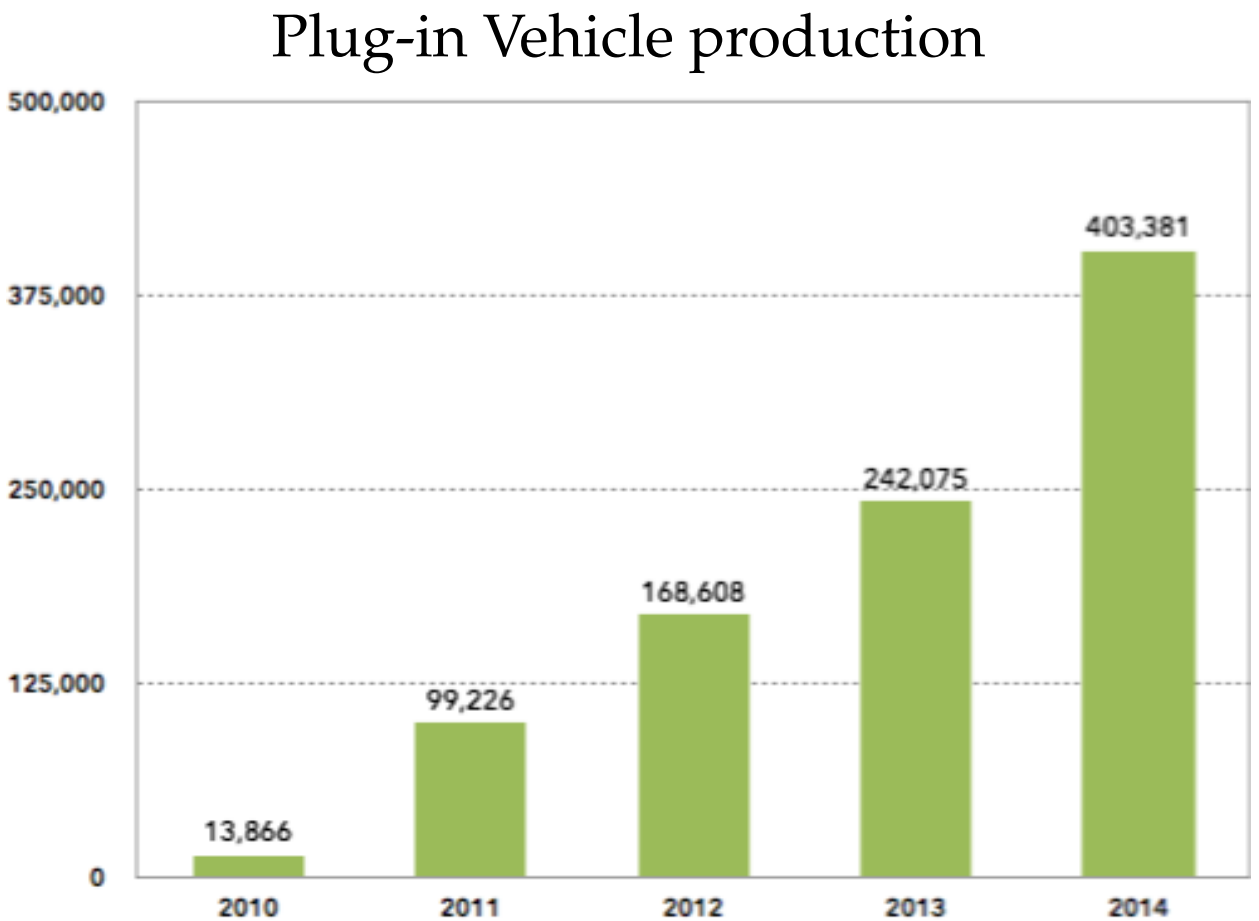


Introduction

Motivation

- Why is route planning for EVs an interesting problem?

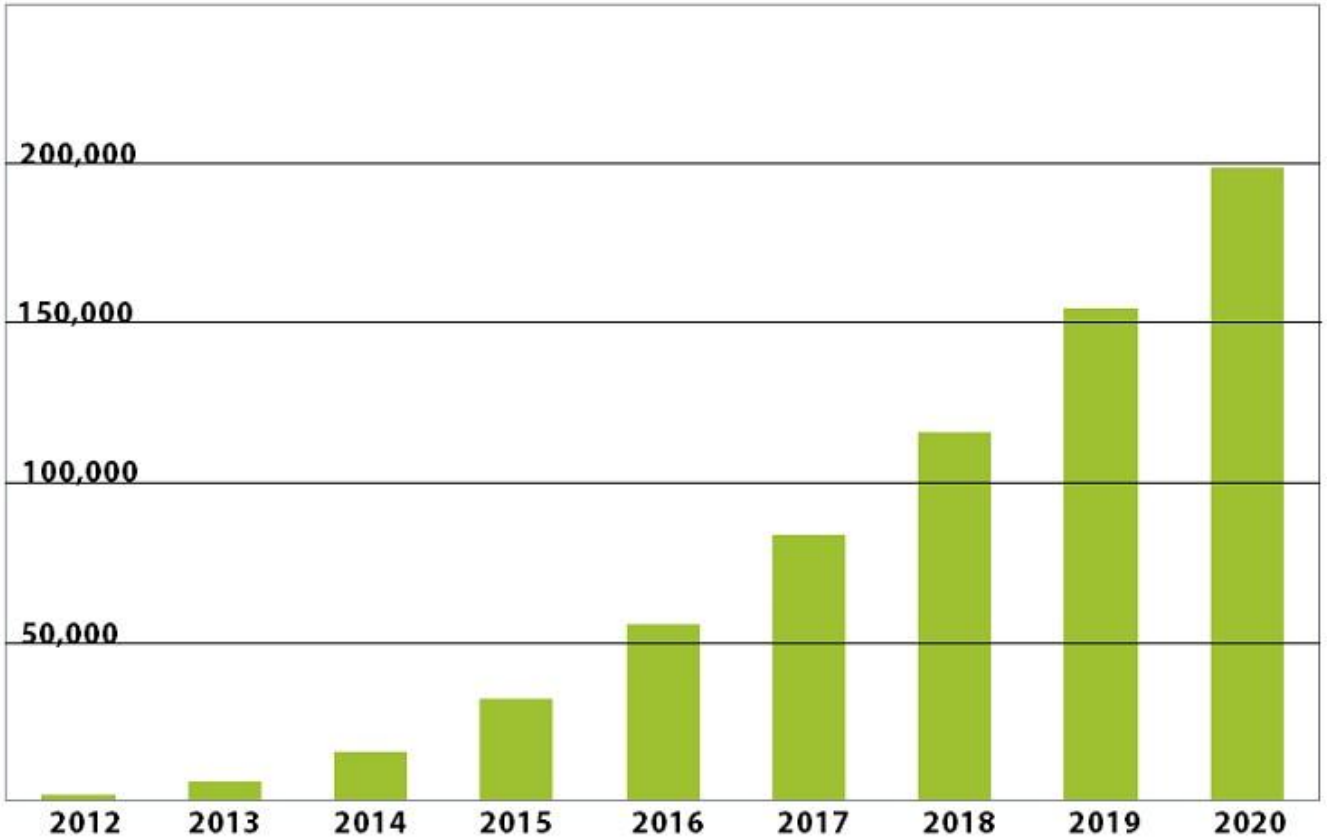


Credit: IHS automotive

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!

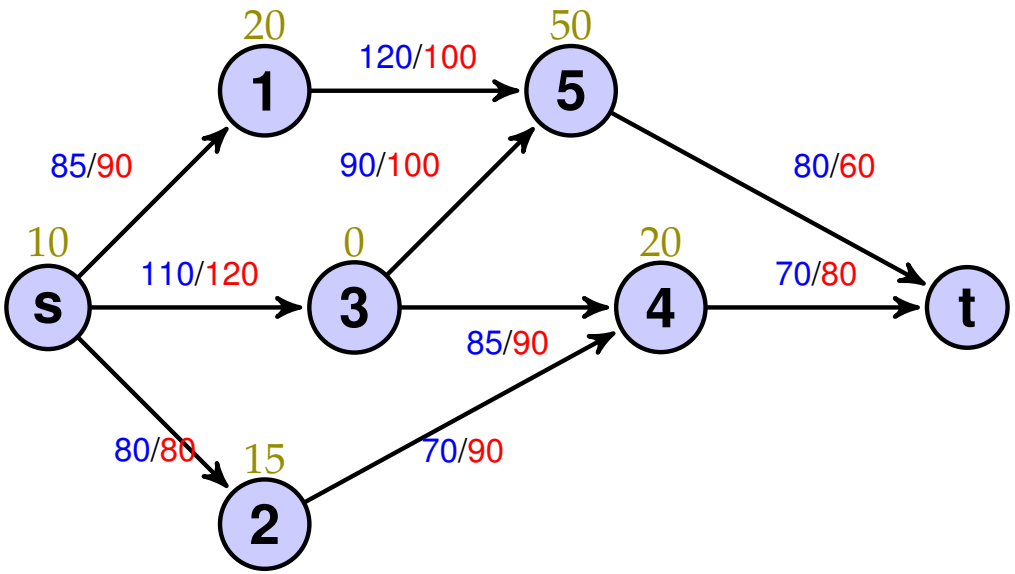
Consequences of this approach:

- 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:

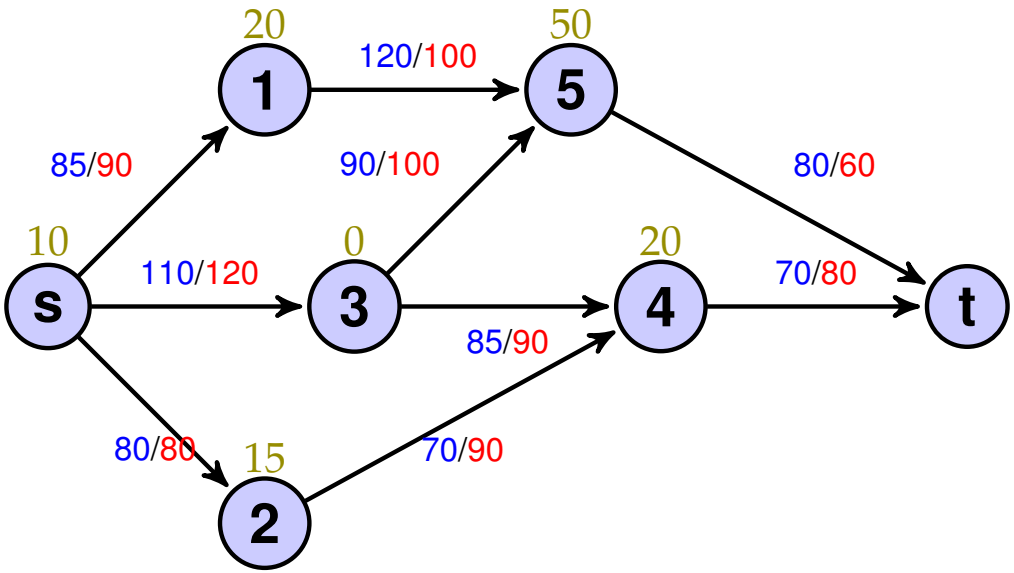
$\langle s, 1, 5, t \rangle$: 285km, 3.5hr

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

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

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

Example

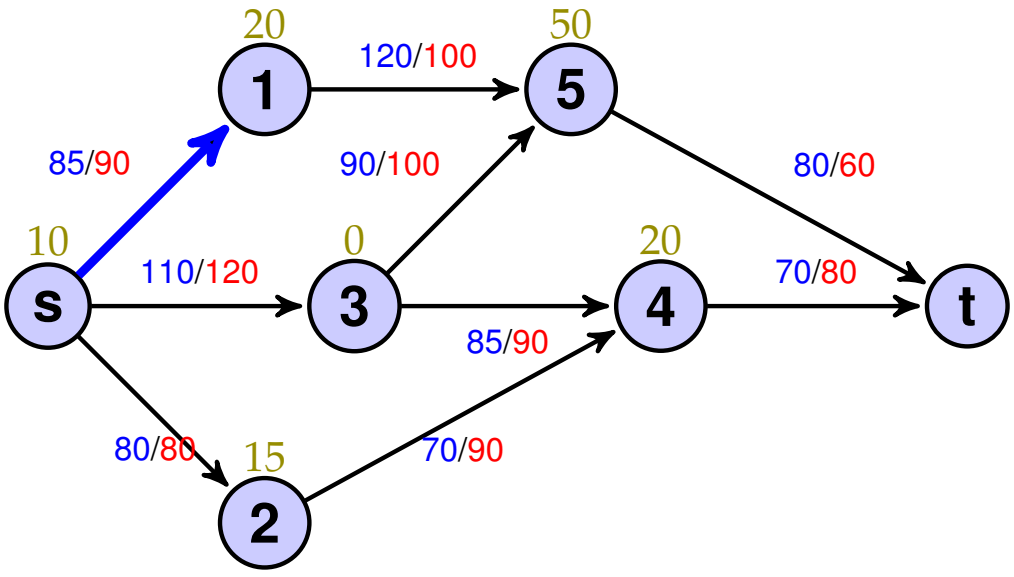


$Q = \{s\}$

Best: s

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

Example

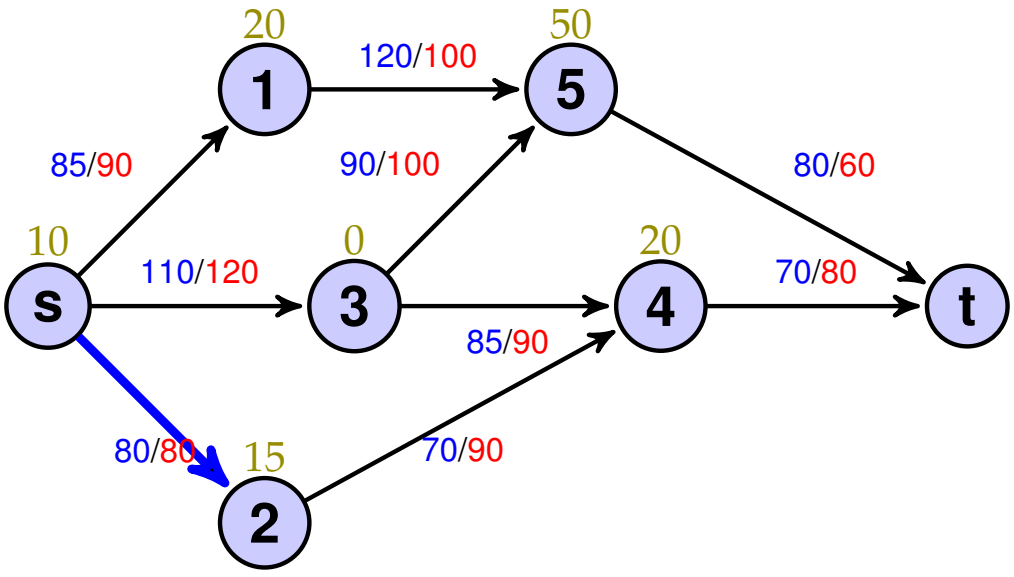


Driving: 90km/hr: 0.94 hr

Drive and charge: Same

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

Example

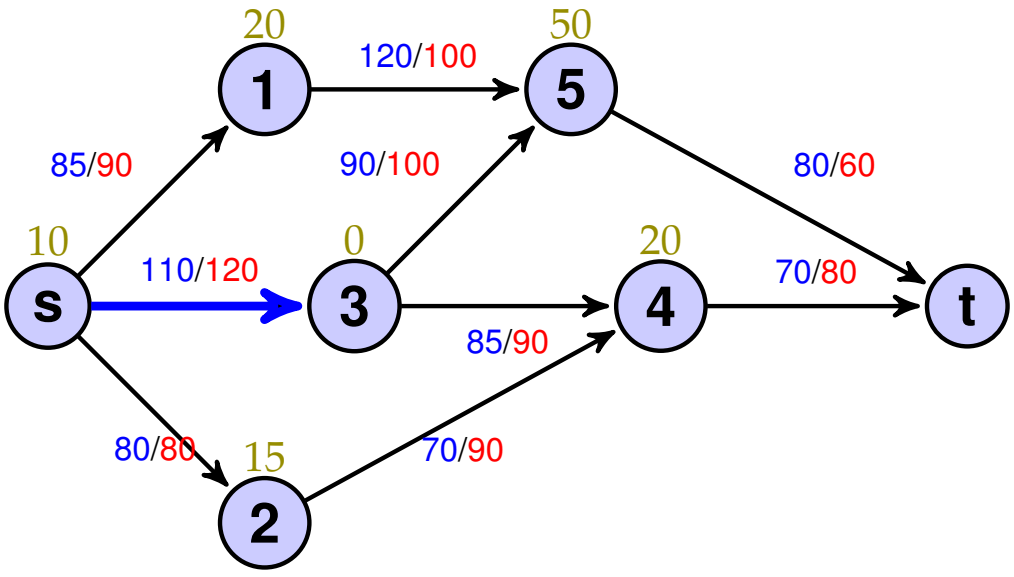


Driving: 80km/hr: 1hr

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

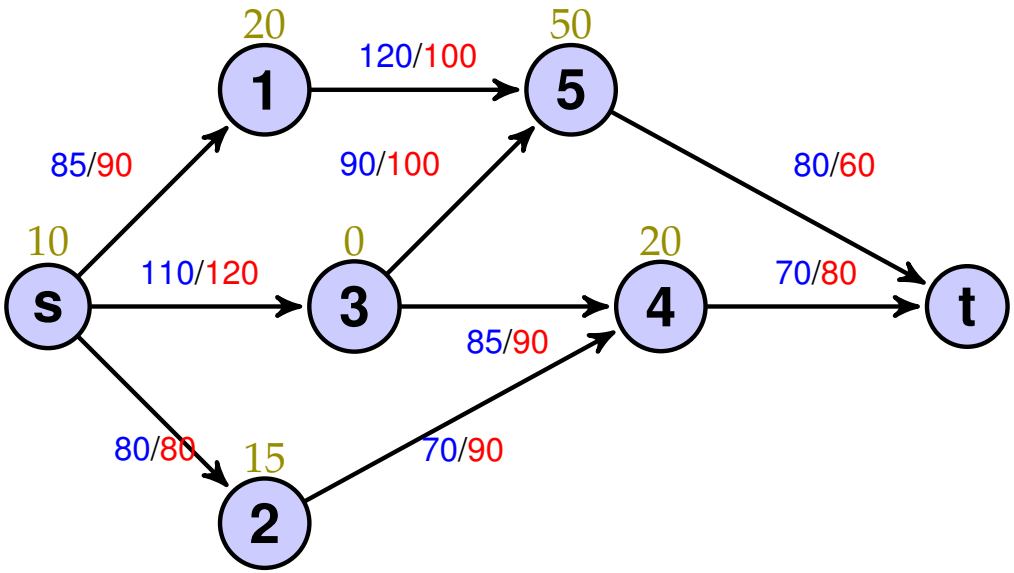


Driving: 120km/hr: 0.92hr

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

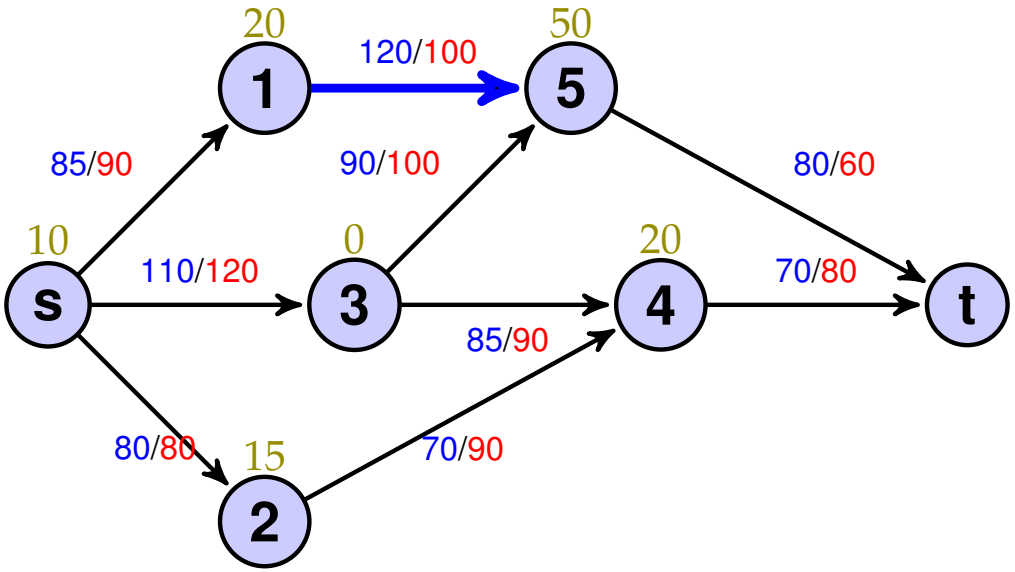


$Q = \{1, 3, 2\}$

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			

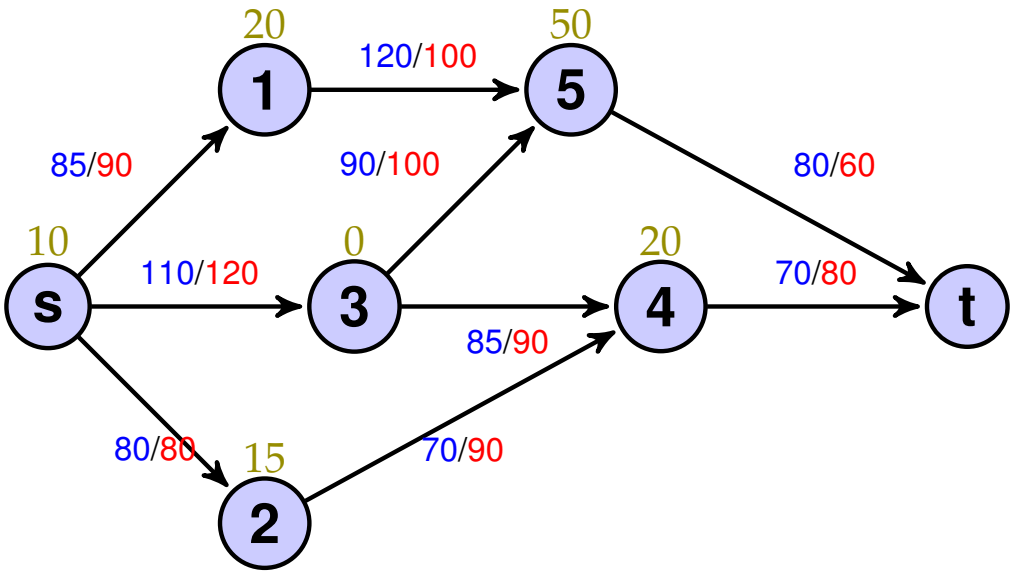
Example



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

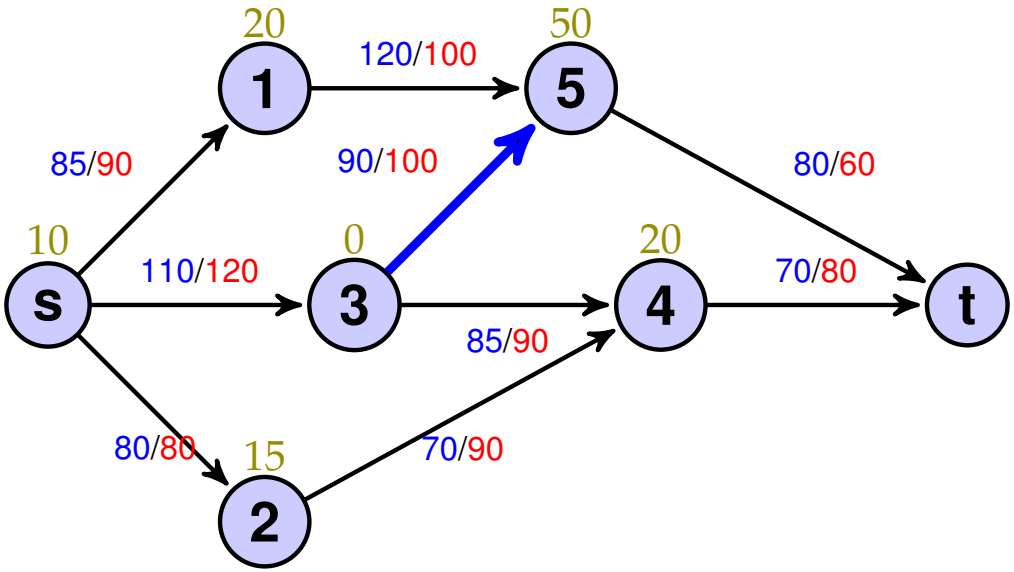


$Q = \{3, 2, 5\}$

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

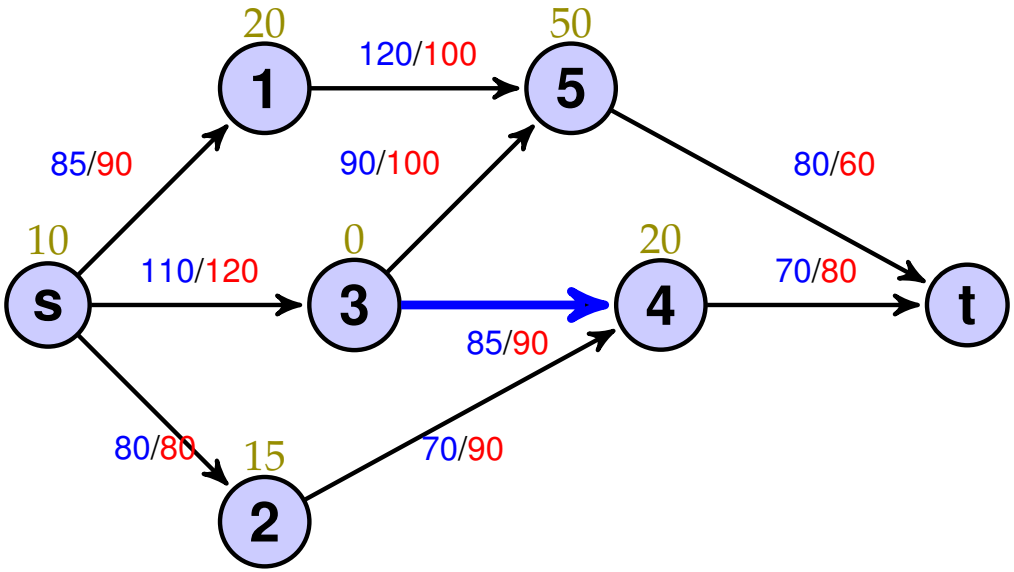


Driving: Not possible!

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

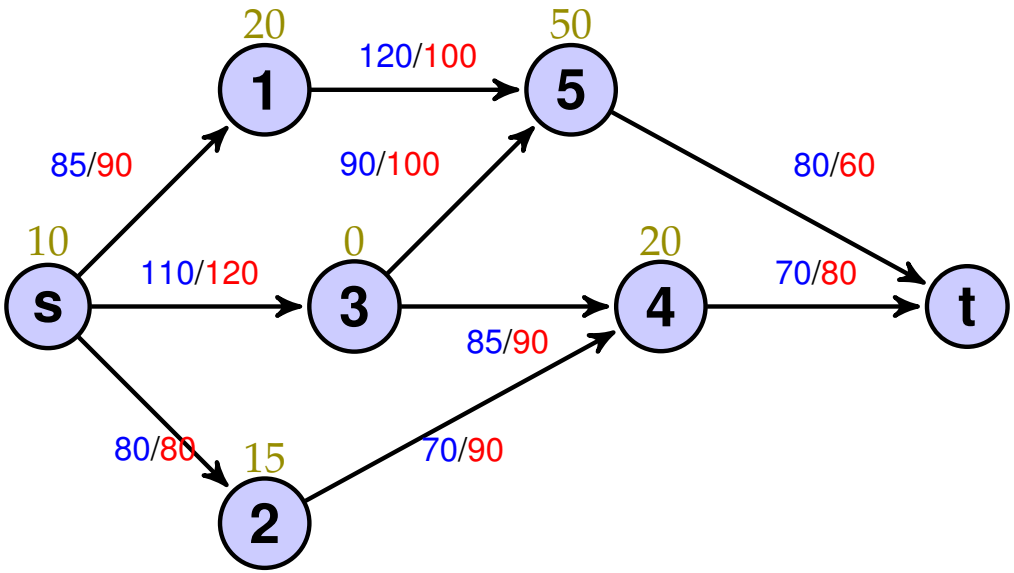


Driving: Not possible

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

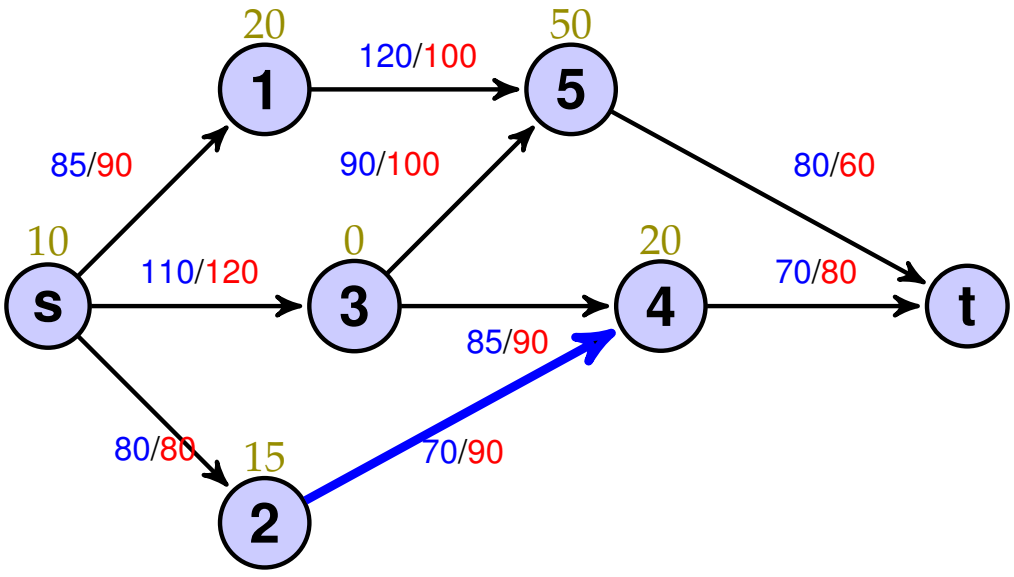


$Q = \{2, 5\}$

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

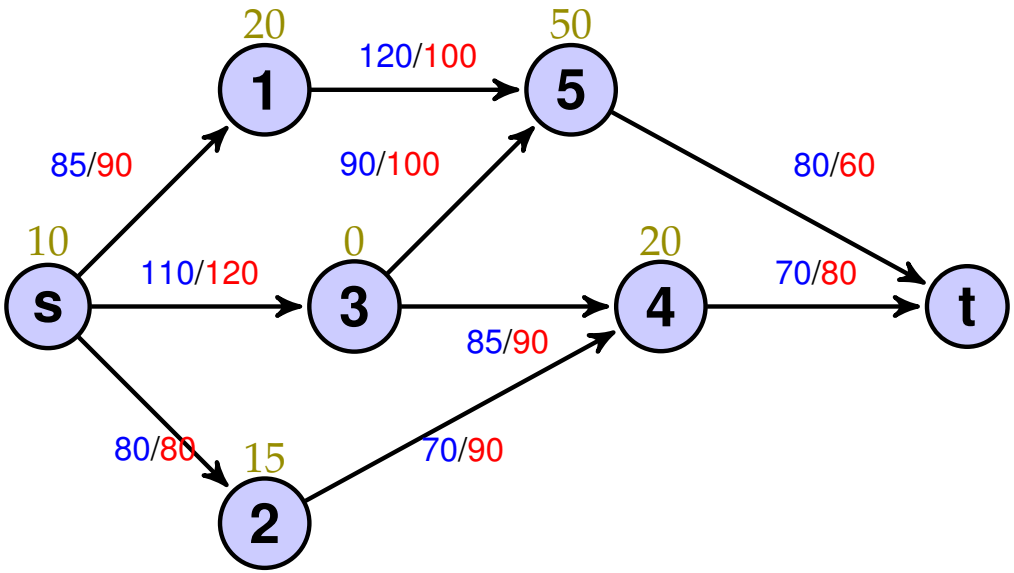


Driving: 90km/hr: 0.8hr

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

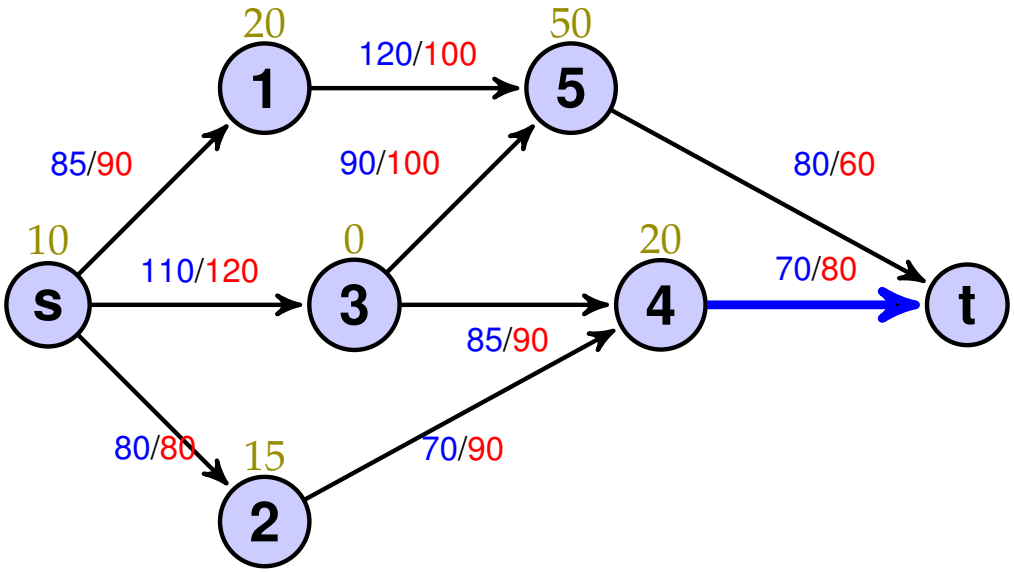


$Q = \{5, 4\}$

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			

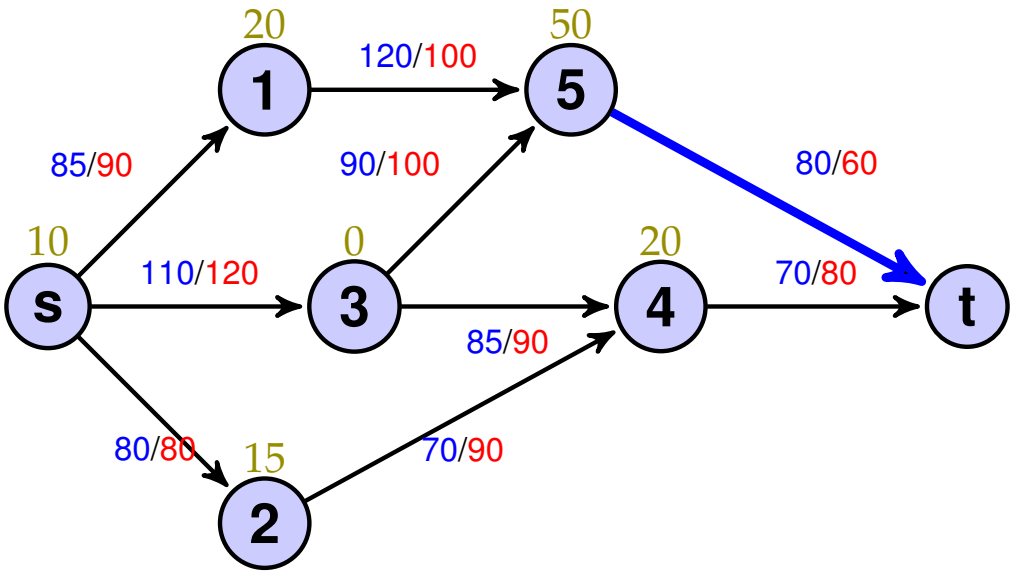
Example



	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

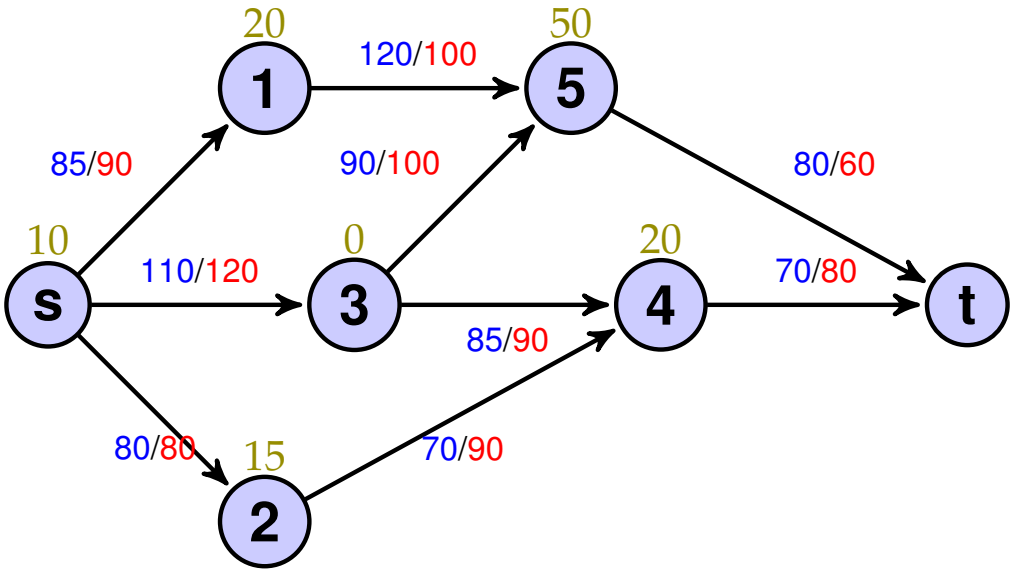


$Q = \{5\}$

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

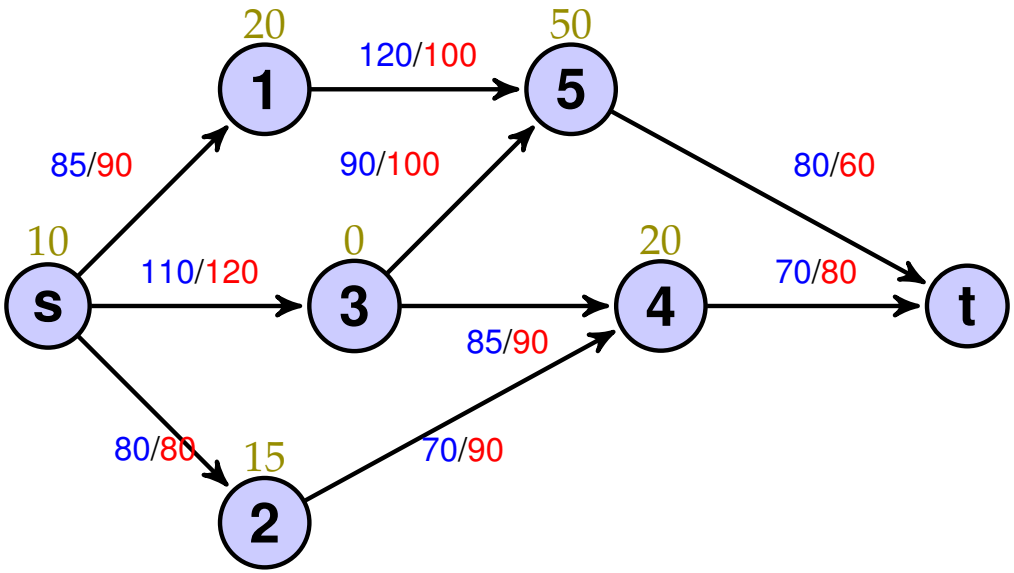
Example



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

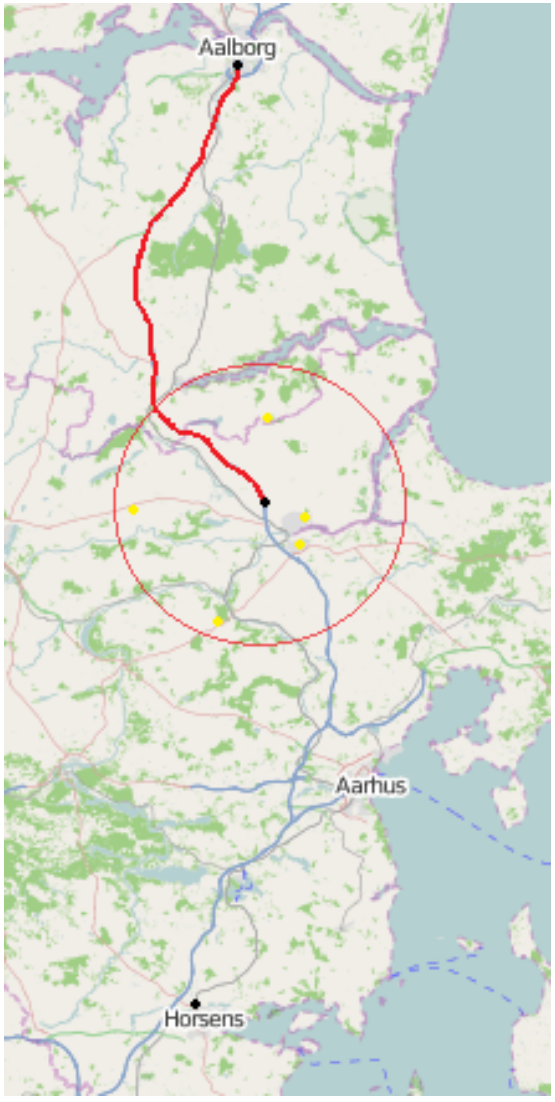
Experiments

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

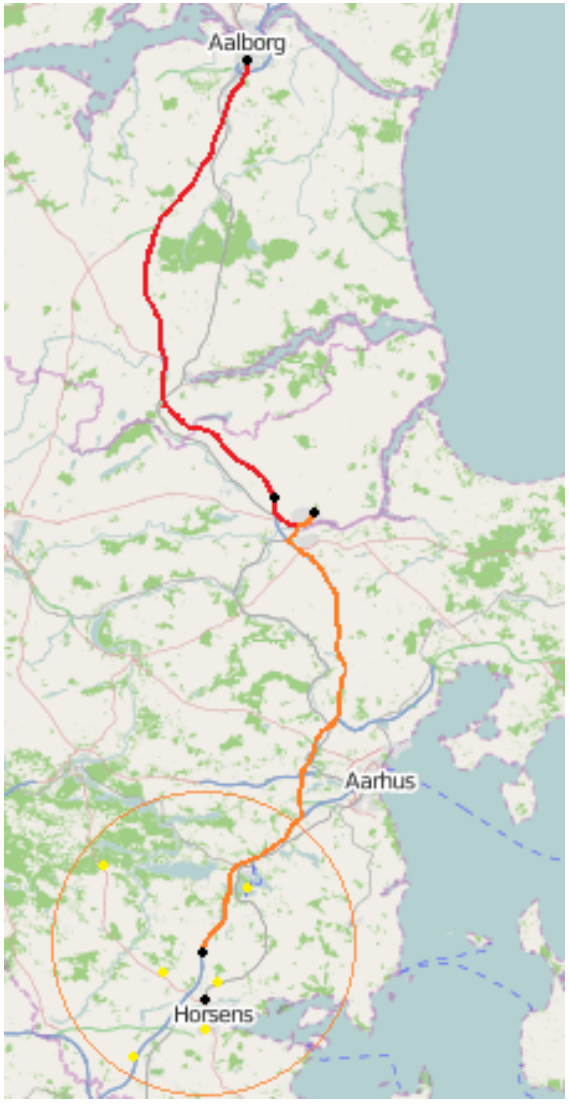
Experiments: The Setup

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

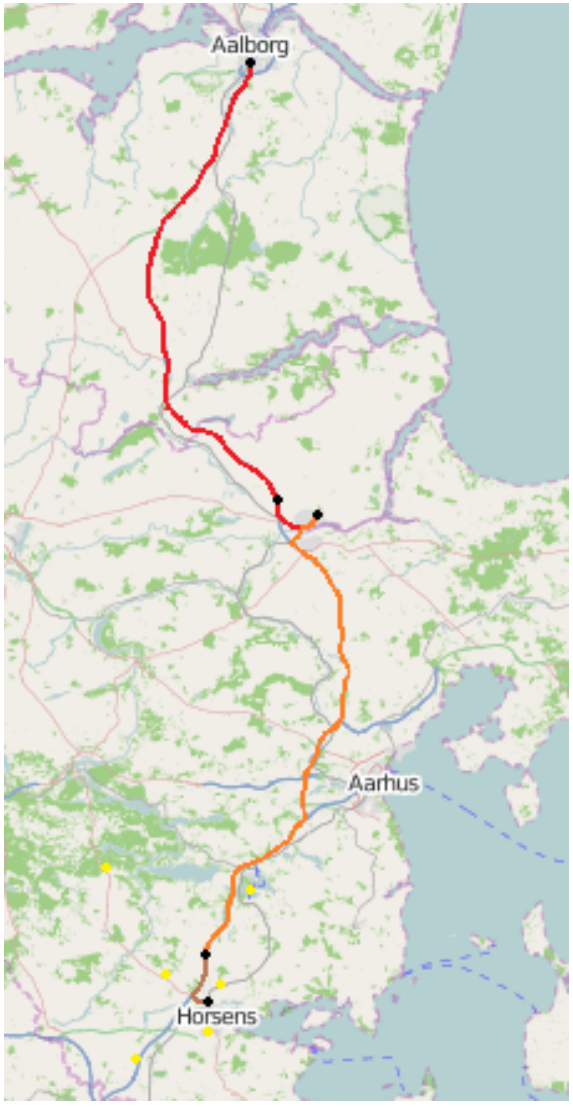
Experiments: The Naive Algorithm



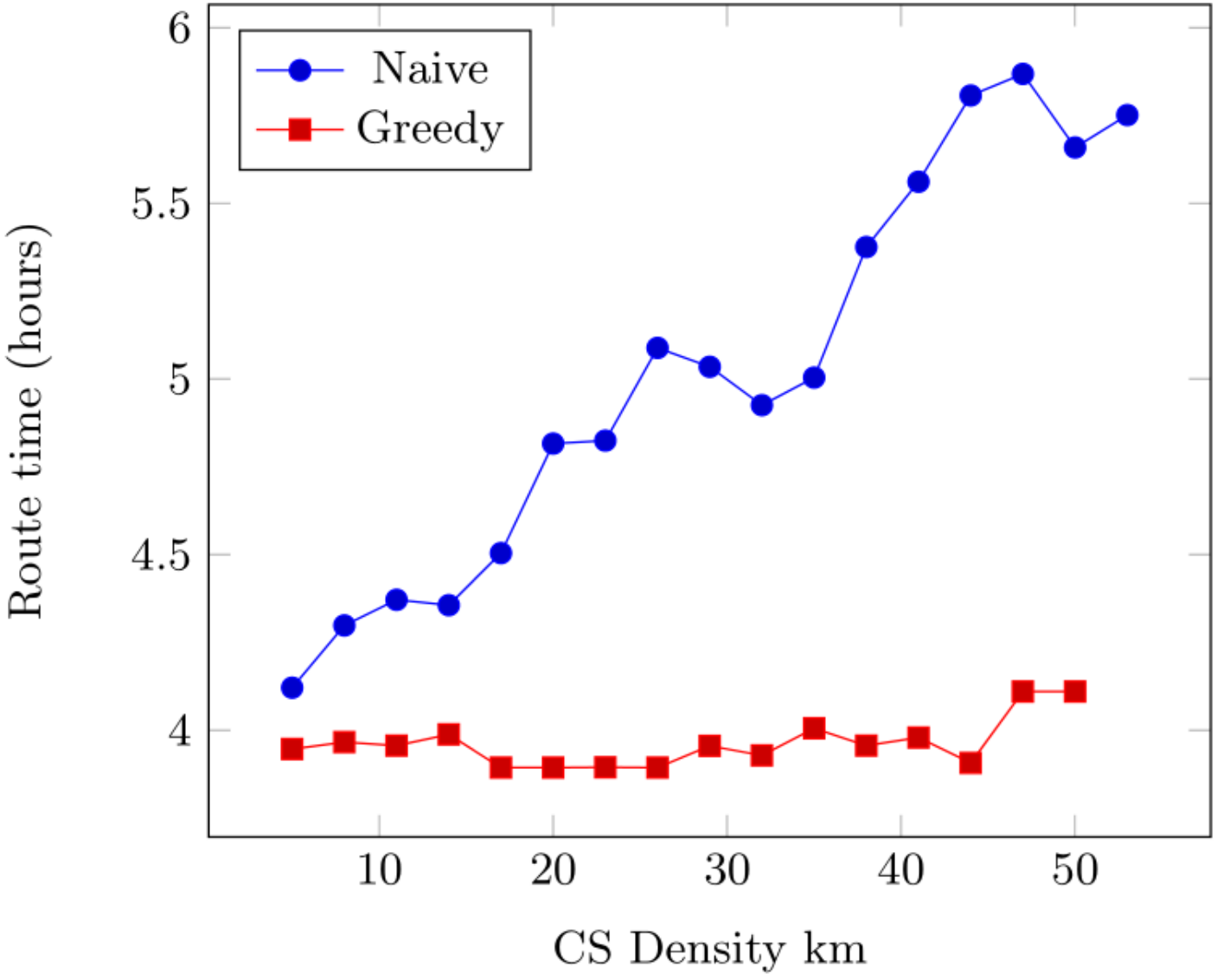
Experiments: The Naive Algorithm



Experiments: The Naive Algorithm



Experiments: Charge station density



Experiments: Charge station density

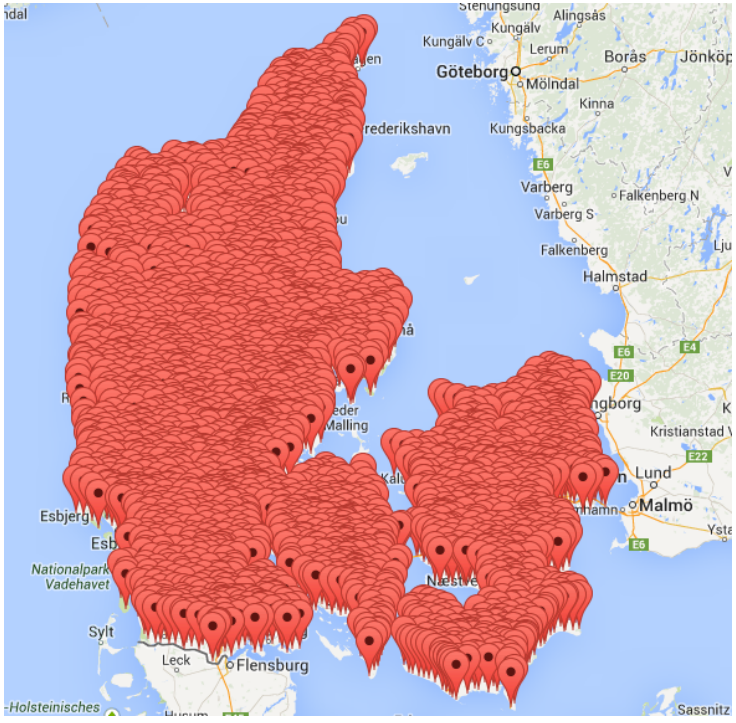


Figure : 5 km between Charge Stations

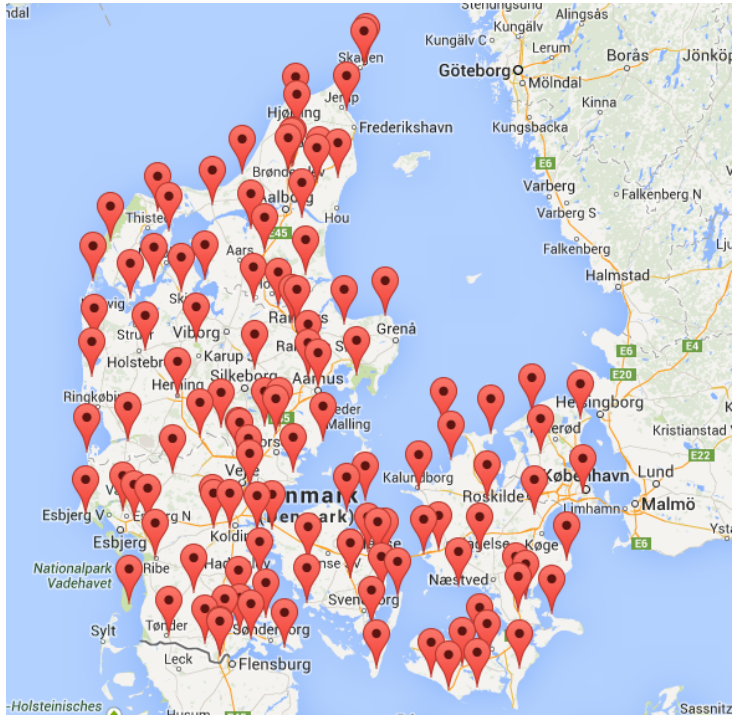


Figure : 30 km between Charge Stations

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

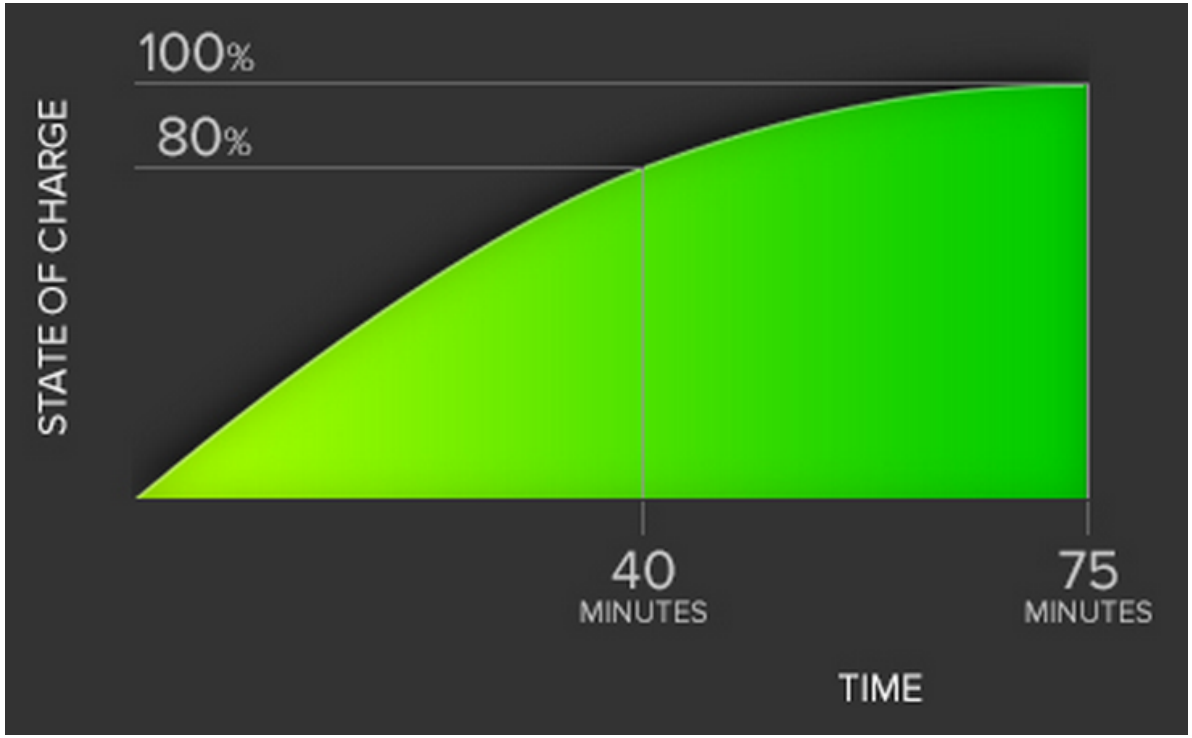
Conclusion

- $0,1\%$ 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