

Range estimation & Trip planning for Battery Electric Vehicles

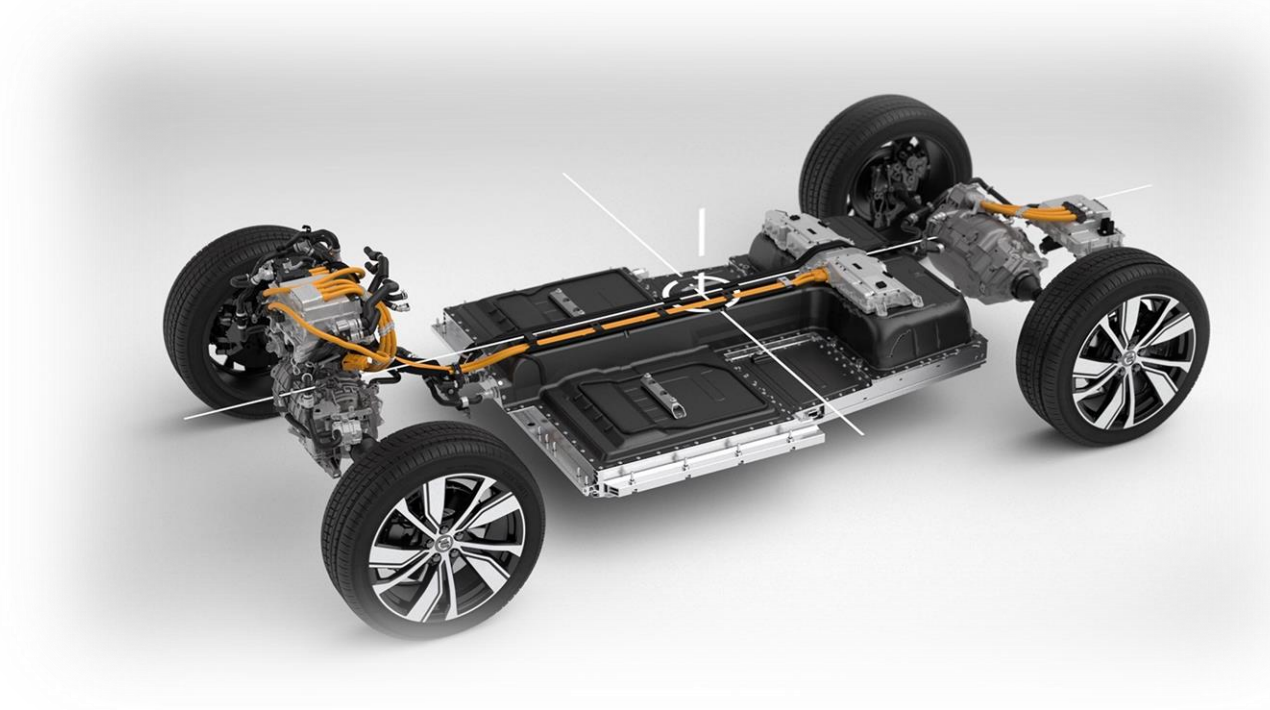


Range Estimation & Trip planning for BEVs, Viktor Larsson, Security Class: Public

2021.10.26

Outline

- Introduction to Volvo Cars
- Background & motivation
- Range in dashboard
- Range & energy apps
- Trip planning in navigation system
- Conclusions





PERSONAL

WE DEVELOP AND BUILD THE PERSONAL
RELATIONSHIPS WITH OUR CUSTOMERS

INITIATIVES AND OBJECTIVES

- Open architecture Android based in-car infotainment services
- Convenient connected services provided via Volvo Cars' mobile app
- Simplified online product offering with care package as standard



SUSTAINABLE

WE COMMIT TO THE HIGHEST
STANDARDS OF SUSTAINABILITY IN
MOBILITY

INITIATIVES AND OBJECTIVES

- Pure electric car company by 2030, with inhouse competence of key components
- 40 per cent reduction of lifecycle carbon footprint for vehicles delivered 2025
- Circular business by 2040 including energy efficiencies and material recycling
- Leader in ethical and responsible business



SAFE

WE PIONEER THE SAFEST, MOST
INTELLIGENT SOLUTIONS IN MOBILITY

INITIATIVES AND OBJECTIVES

- Our vision is that no one should be killed or seriously injured in a new Volvo car
- Safe AD implementation
- Leadership in human behavior safety

VOLVO CARS AT A GLANCE 2020

661,700
CARS SOLD39,000
EMPLOYEESSEK 263BN
REVENUESEK 8.5BN
EBITGlobal Presence With Sales
in Over 100 Countries

AMERICAS

California
R&D and Design CentreCharleston
Models: S60New Jersey
Americas Headquarters

EMEA

Gothenburg (HQ)
Global Headquarters
R&D and Design Centre
Car ProductionModels: V60, V60 Cross
Country, V90, V90 Cross
Country, XC60, XC90Ghent
Model: XC40

APAC

Bangalore
Models: S90, XC60, XC90Kuala Lumpur
Models: S60, V60, S90,
XC60, XC90Chengdu
Models: XC60Luqiao
Model: XC40Shanghai
APAC Headquarters
R&D and Design CentreDaxing
Models: S60, S90

THE VOLVO CAR GROUP – A SET-UP FOR THE FUTURE

VOLVO CARS

Fast growing premium OEM



EVOLVING TRADITIONAL CAR SALES BUSINESS

Care by Volvo

My car always & My car sometimes



Online sales

Site to Store

Zenseact
(prev Zenity)ADAS / AD full
software stack
developer¹

STRATEGIC AFFILIATES

Polestar
(~50%)Spearheading
electrification with
pure progressive
performance carsLYNK & CO
(30%)New youthful brand
going global to
address 65 M
mass market

Volvo Cars – Consolidated

Strategic affiliates – Non-consolidated

Background & Motivation

- The range is simple to compute...
 - So why all the fuss?
- Certified range
 - Different test cycles on the three major markets (EU/US/China)
 - EU/China test cycle has low average speed & low climate loads
 - Test ends when vehicle cannot follow the test cycle (not when 0% is shown!)
- “Real world range” is typically significantly lower than certification

Vehicle Model	Actual*	Certified WLTC	$\frac{\text{Actual}}{\text{Certified}}$	Configuration
Audi E-tron	331 km	446 km	0.74	AWD
Mercedes EQC	312 km	417 km	0.75	AWD
Jaguar I-Pace	358 km	470 km	0.76	AWD
Tesla Model 3	434 km	560 km	0.78	AWD
Nissan Leaf	334 km	385 km	0.87	FWD
Kia e-Niro	410 km	455 km	0.90	FWD

*Benchmark test in the UK by CarWow
<https://www.youtube.com/watch?v=ZH7V2tU3iFc&t=145s>

$$R_{km} = \frac{\eta_{batt} \cdot E_{batt}^{wh}}{C_{km}^{wh}}$$

$$C_{km}^{wh} = \frac{P_{prop} + P_{aux} + P_{climate}}{3.6 \cdot v_{m/s}}$$

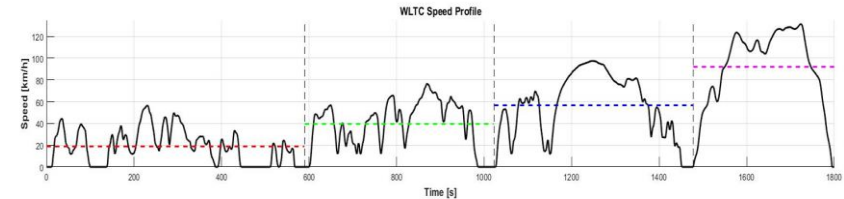
Volvo XC40 Recharge

Upp till **421 km**
 Räckvidd, ren eldrift*

* Räckvidd beräknas enligt WLTP.

Up to **223 Miles** (359 km)
 of Pure electric range**

** Range is according EPA driving cycle!



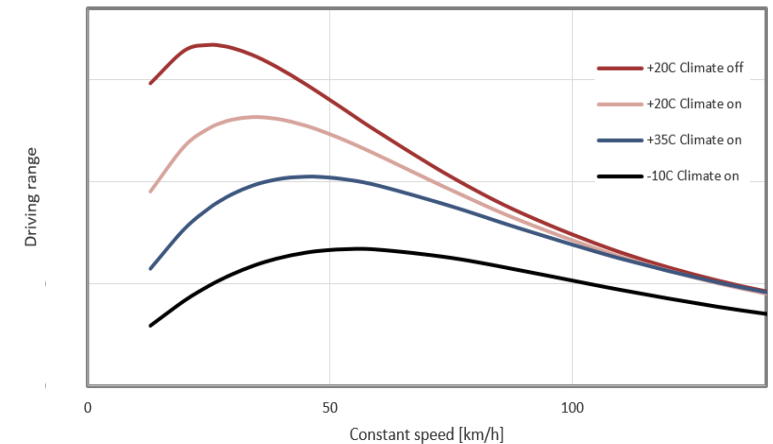
Background & Motivation

- Batteries are heavy, large and expensive...
 - The size of the battery pack will be limited for the foreseeable future
- Range is significantly reduced at cold ambient temperatures
 - Higher rolling resistance & air drag
 - Cabin heating costs a lot of energy, i.e., no waste heat from the engine
- A cold battery has reduced performance
 - Higher losses and lower power & energy availability
 - Charging performance is significantly reduced
- Range anxiety
 - Fleet data indicates very limited amount of driving below 15% State of Energy
 - Reliable range estimation & trip planning functions can help mitigate the effect

$$R_{km} = \frac{\eta_{batt} \cdot E_{batt}^{wh}}{C_{km}^{wh}}$$

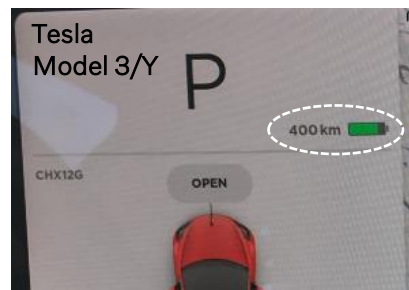
$$C_{km}^{wh} = \frac{P_{prop} + P_{aux} + P_{climate}}{3.6 \cdot v_{m/s}}$$

Estimate of range as a function of speed and outdoor temp



Range in Dashboard

VOLVO



Range estimate in Dashboard

- Most OEMs display at least one range estimate in the dashboard/instrument cluster/centre stack display
- Two different approaches are typically used, varies between brand and market

a. “Certified range”

- Calculated assuming a constant energy consumption (typical or certified)
- Range is a “proxy” for SoE & State of Health (SoH)
- Consistent behavior, i.e. fully charged battery will always give the same range
- Will “always” be wrong, i.e. $\Delta \text{range} \neq \text{driven distance}$

b. “Best estimate range”

- Calculated based on historical energy consumption & predicted driving conditions
- More difficult to assess battery SoH
- Inconsistent behaviour, i.e. fully charged battery might show different range every time
- Will on average be correct over the long term, i.e. $\Delta \text{range} \approx \text{driven distance}$



Certified



Polestar

Best estimate



PORSCHE



JAGUAR



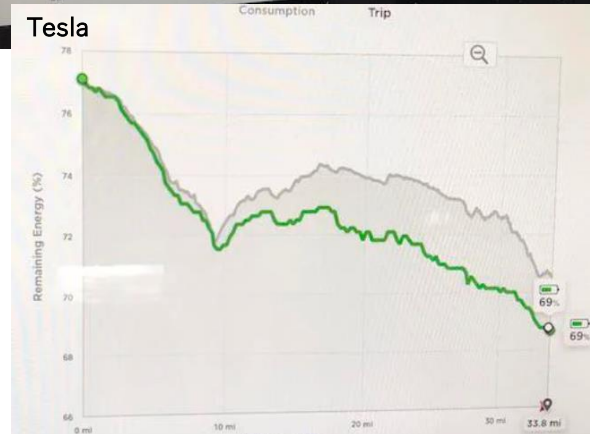
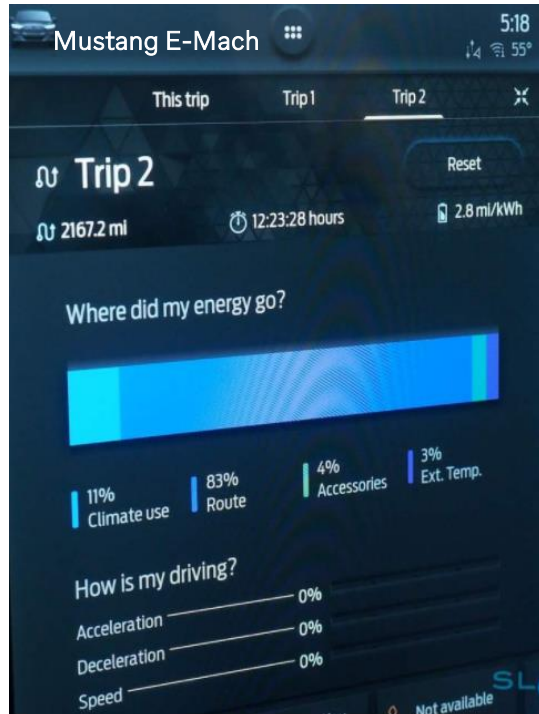
Mercedes-Benz



Range estimate in Dashboard

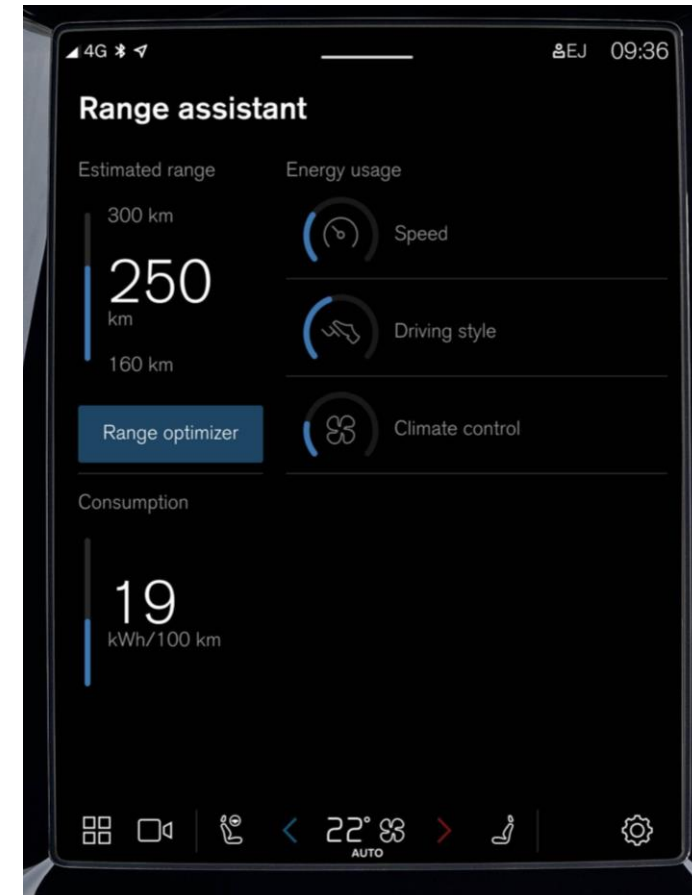
- **“Certified range”**
 - Trivial to compute and implement
 - Main challenge is the variant handling (market, battery, tophat, powertrain,...)
- **“Best estimate range”**
 - Estimate based on historical consumption stored in ECU memory
 - Not very difficult to develop an estimate that is correct “on average”
 - Challenges are related to user experience
 - Expectation of an immediate range update each time a setting is changed
 - Most combinations of settings & ambient conditions are never excited
 - For example: 1,211,392 possible combinations of climate settings in front row alone...
 - Challenge to combine feedback (historical consumption) with feed-forward of expected change in consumption due to change of settings

Range App in Centre Stack Display

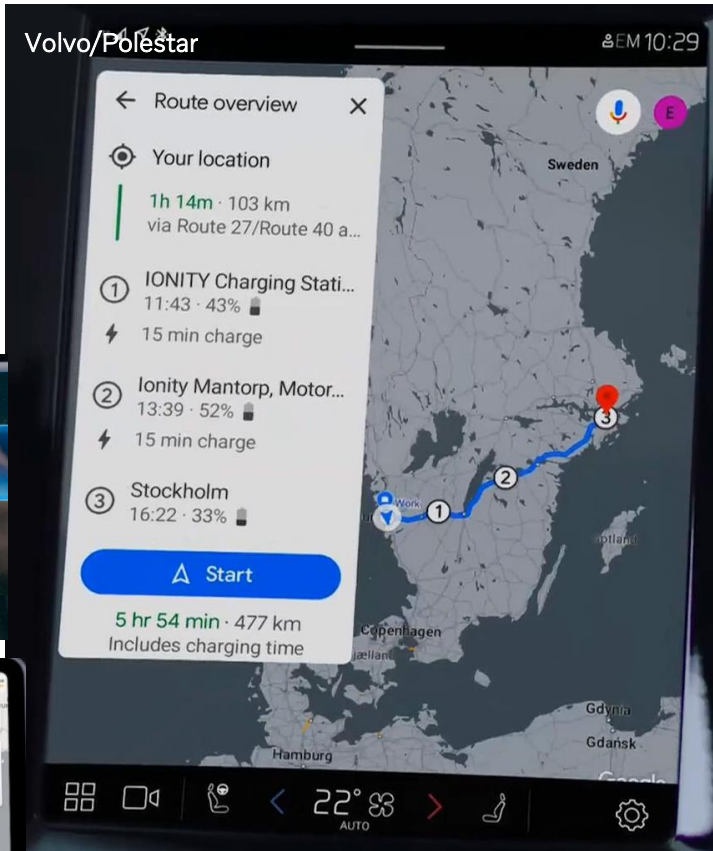
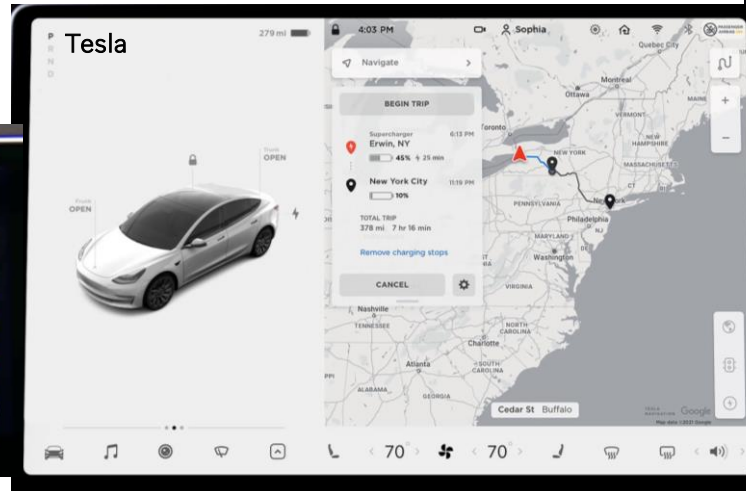
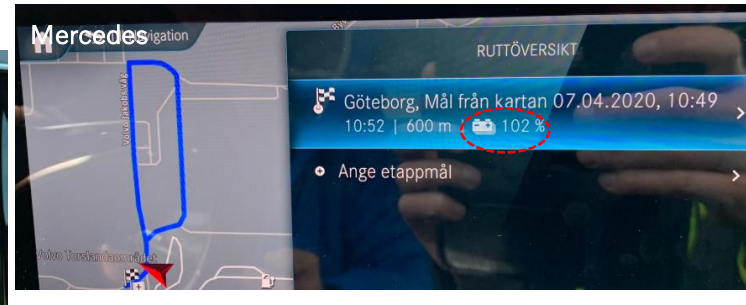
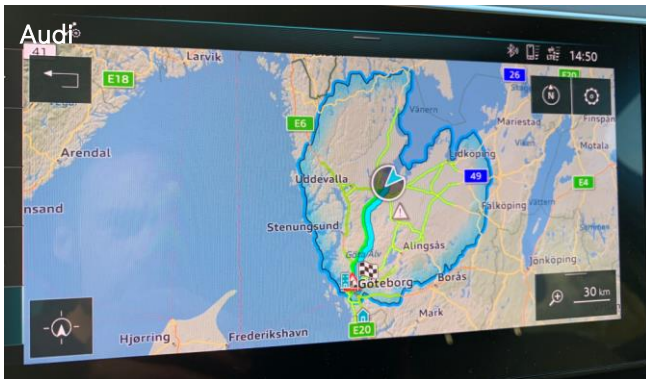


Range App in Centre Stack Display

- Provides more detailed information regarding range & consumption
 - Help the user to understand why the range might be lower than the certification figure
 - Released as an app via Over The Air (OTA) update starting week 40 this year
- Estimated range
 - High: Low average speed with climate off
 - Current: Based on historical consumption, amount of history proportional to SoC
 - Low: Motorway speed with default settings climate at current ambient temperature
- Energy usage
 - Speed: Short term average speed
 - Driving style: Standard deviation of the acceleration
 - Climate: Modelled steady state consumption at current ambient temperature
- Consumption
 - “Instant” energy consumption
- Range optimizer
 - Activates Eco-climate, which reduces climate consumption

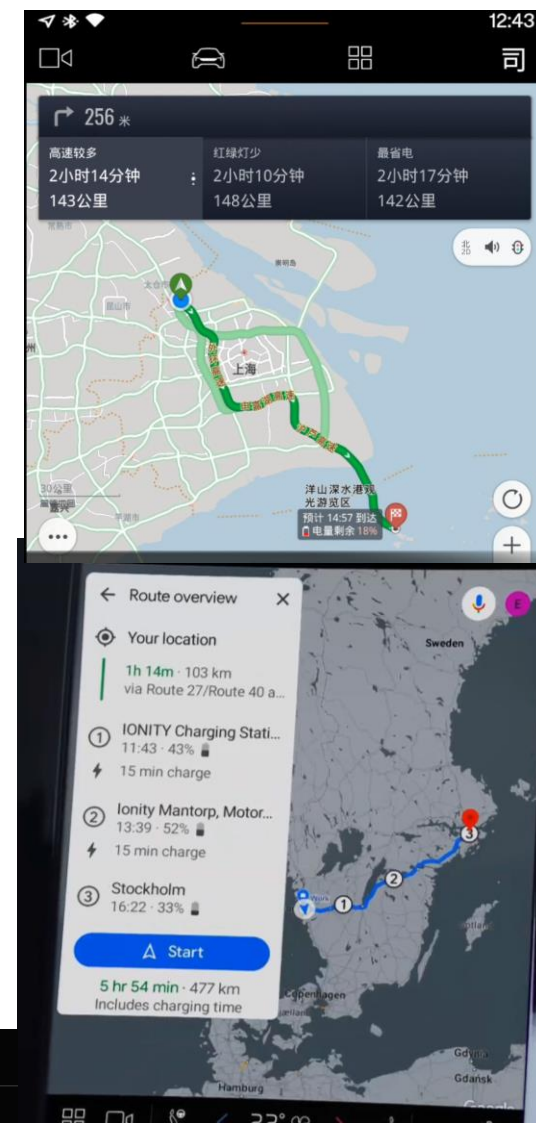


Trip Planning in Navigation System



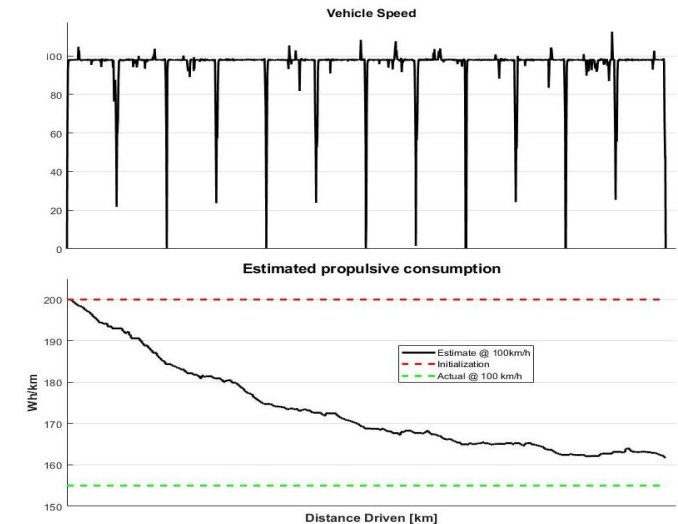
Trip Planning in Navigation System

- Important that the driver can plan longer trips and make an informed decision of where to charge (if needed)
- Integrated with the navigation system
 - Different suppliers for different markets (China, South Korea, Google for remaining markets)
- System is based on a common Vehicle Energy Model
 - Volvo and supplier has agreed on a common model (not all suppliers use the same model)
 - Volvo is responsible for providing the model parameters
 - Navigation supplier is responsible for routing & calculating the energy consumption
 - Navigation supplier provides information regarding destination, charging station & route
- Enabler for additional functionalities
 - Battery pre-heating before fast charging station
 - Range coaching, e.g. decrease speed, turn off climate to reach destination, ...



Trip Planning in Navigation System

- To obtain a good overall prediction accuracy the parameters for the vehicle energy model should be updated online in each specific vehicle
 - Propulsive consumption, climate consumption, vehicle mass, battery energy, ...
 - Tires & driving style, climate settings, number of passengers, degradation, ...
- Possible to obtain a decent accuracy with a relatively simple model and parameter adaptation algorithms
 - Data from vehicle fleet indicates that +/- 10% accuracy is frequent
 - Large prediction errors exist due to many different reasons (speeding, towing, re-routing, congestions, ...)
- Challenges
 - Towing, roof box, over/under-speeding, ...
 - Conflicting feed-back loops between vehicle and navigation system e.g. battery pre-heating could lead to a re-routing
 - Range estimate based on navigation data can lead to changed value due to re-routing or changed traffic conditions ahead of vehicle



Trip Planning in Navigation System

However, the navigation aspect using the gold standard Google Maps. Other automakers have systems that sort of do the same thing, but nowhere near the robust nature of this Google system. It is the best I've experienced by far.

<https://driving.ca/reviews/road-test/long-term-test-update-2021-volvo-xc40-recharge>

It's also uniquely tailored to running the infotainment system in an electric vehicle. When you ask Google to navigate you to a certain location, the Android-powered operating system will take into account your battery levels and incorporate charging stations that are available along the way. That should go a long way toward quelling any range anxiety you may have.

<https://www.theverge.com/2020/12/22/22195499/volvo-xc40-recharge-ev-suv-first-drive-specs-price>

Räckvidden anges bara i återstående procent och den momentana förbrukningen syns inte. Jag får själv med hjälp av tidigare förbrukningssnitt i färddatorn räkna ut kvarstående räckvidd, eller ta hjälp av Google-assistenten, som med fin precision anger hur mycket kraft som bör återstå i batterierna när jag kommer till min destination. När återstående kapacitet är 20 procent eller mindre, anges dock kvarvarande räckvidd i km – varför inte hela tiden?

<http://www.gronabilister.se/tester/bilar/2021/volvo-xc40-recharge>

First seen on the Polestar 2, this system is far more than 'Android Auto turned up to 11'; it's properly hooked up to the car's infrastructure, programming an alarmingly accurate estimate on how much battery you'll have left at the end of a journey into the navigation, for example. And, of course, that ecosystem is all Google-based so, assuming you tick the data-release boxes, it's properly stitched into your life.

<https://www.autoexpress.co.uk/volvo/xc40/353320/new-volvo-xc40-p8-recharge-2020-review>

Conclusion & Outlook

- The focus on certified range results in unrealistic customer expectations
 - Might indicate how many times it is possible to drive a sub-urban commute at 20°C...
 - Does not indicate how far it is possible to drive at highway speeds, regardless of season!
- Not trivial to provide clear and unambiguous information
 - Range in dashboard will typically not be consistent with predicted SoE at destination in navigation system
 - Turning off climate gives limited range gain at highway speeds, but can be significant at low speeds
- There are many different opinions regarding range...
 - Best estimate or certified?
 - Should changed settings immediately affect the range?
 - Should best estimate range be used for coaching or for planning?
 - Should the user be allowed to select which range figure to show?

V O L V O