EU-Commission JRC Contribution to EVE IWG:

In-vehicle battery durability

Web-Meeting of the GRPE Informal Working Group
Electric Vehicles and the Environment (EVE)

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29th June 2020

Presentation Summary (1/2)

Follow-up of the JRC activities for contribution to the EVE IWG under the "in-vehicle battery ageing" topic

Current Status (Jan-March 2020), i.e. what's old:

- Exploring power fade models already implemented in TEMA
- Exploring V2G ageing effect on top of normal usage of the vehicles
- Exploring comparison with new real-world data
- Exploring new battery chemistry models

Presentation Summary (2/2)

Follow-up of the JRC activities for contribution to the EVE IWG under the “in-vehicle battery ageing” topic

Current Status (May 2020), i.e. what’s new:

- Exploring comparison with new real-world data

Summary of the logical passages

#1

Performance-based models

(validated on exp. at cell-level)

#2

Vehicle reference architectures

(from cell-to-vehicle)

#3

Real-world Driving data

#4

Durability Scenarios

(Yrs and/or km to EoL)

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Performance based models (SotA)

	Capacity fade		Power fade	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + spinel Mn	Wang et Al. (2014);		-	Wang et Al. (2014);
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Calendar + Cycle (4 Combinations):

#1 (LiFePO4): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Wang et Al. (2011) model for cycle;

#2 (LiFePO4): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Sarasketa-Zabala et Al. (2015) model for cycle;

#3 (NCM + Spinel Mn): Wang et Al. (2014) for calendar plus Wang et Al. (2014) for cycle;

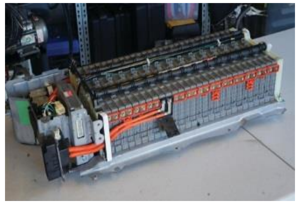
#4 (NCM-LMO): Wang et Al. (2014) for calendar plus Cordoba-Arenas et Al. (2015) for cycle

Implementation of the performance based models into JRC TEMA (assumptions 1/2)

Vehicle Electric Architectures (examples)

PHEV 1

PHEV 2

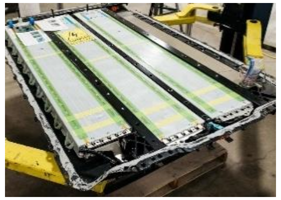


PHEV 3

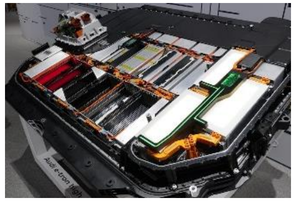
BEV 1

BEV 2

BEV 3



BEV 4



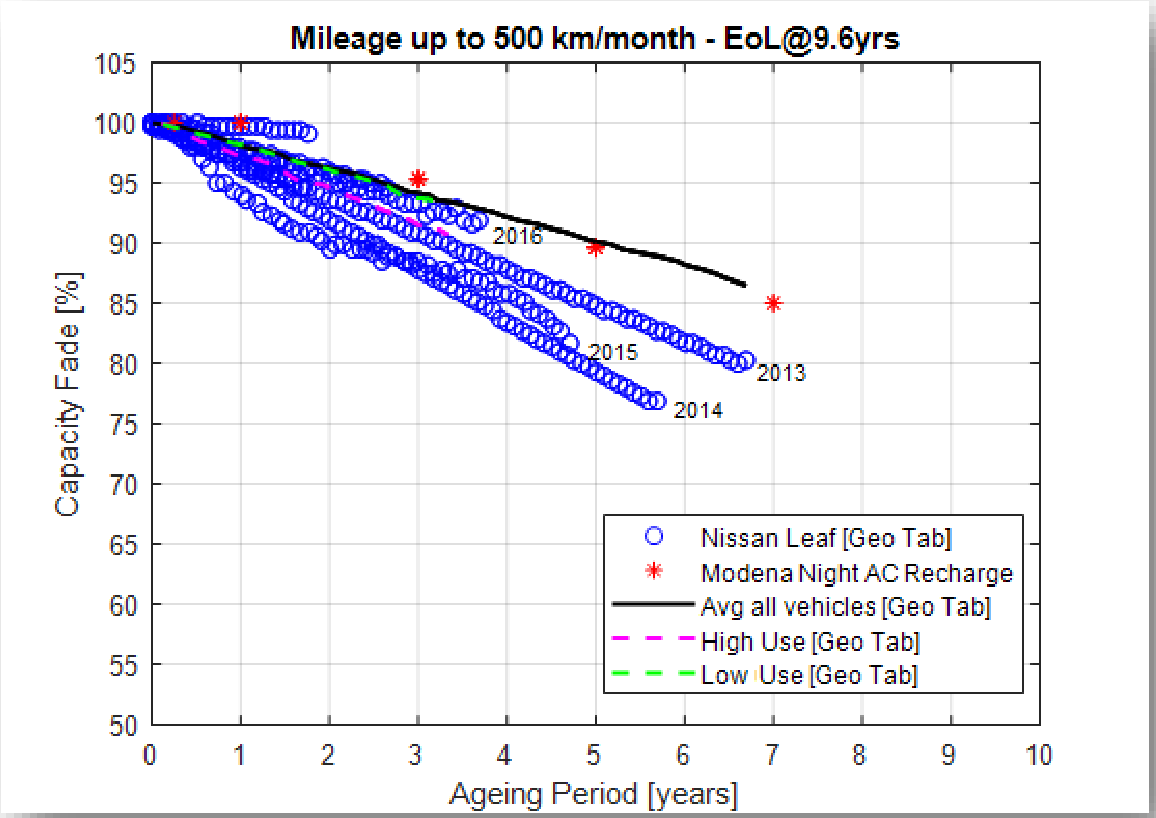
	Vehicle Type	Battery Size [Wh]	Battery Shape	No. of Cells [#] and Type	Reference Voltage [V]	Electric Architecture	Usable Energy at BoL [Wh]	Usable Energy at EoL [Wh]	Reserve [% of battery capacity]	Energy consumption [Wh/km]
HP PHEV	PHEV 1	16,000	T-shaped	192 – pouch	365	2P-96S	12,000	9,600	25%	205
Mid-sized PHEV	PHEV 2	8,800	Parallelepiped	95-Prismatic	351	95S	6,600	5,280	25%	160
Mid-sized PHEV	PHEV 3	12,000	Parallelepiped	80-Prismatic	300	80S	9,000	7,200	25%	194
Mid-sized BEV	BEV 1	24,000	Parallelepiped	192 – pouch	360	48S-2P-2S	18,000	14,400	15%	210
HP large-sized BEV	BEV 2	85,000	Flat	6,912 - cylindrical	345	16S-72P-6S	63,750	51,000	15%	235
HP large-sized BEV	BEV 3	75,000	Flat	4,416 - cylindrical	345	4S-46P-23|25S	56,250	45,000	15%	180
HP large-sized BEV	BEV 4	95,000	Flat	432 – pouch	396	4P-108S	71,250	57,000	15%	262

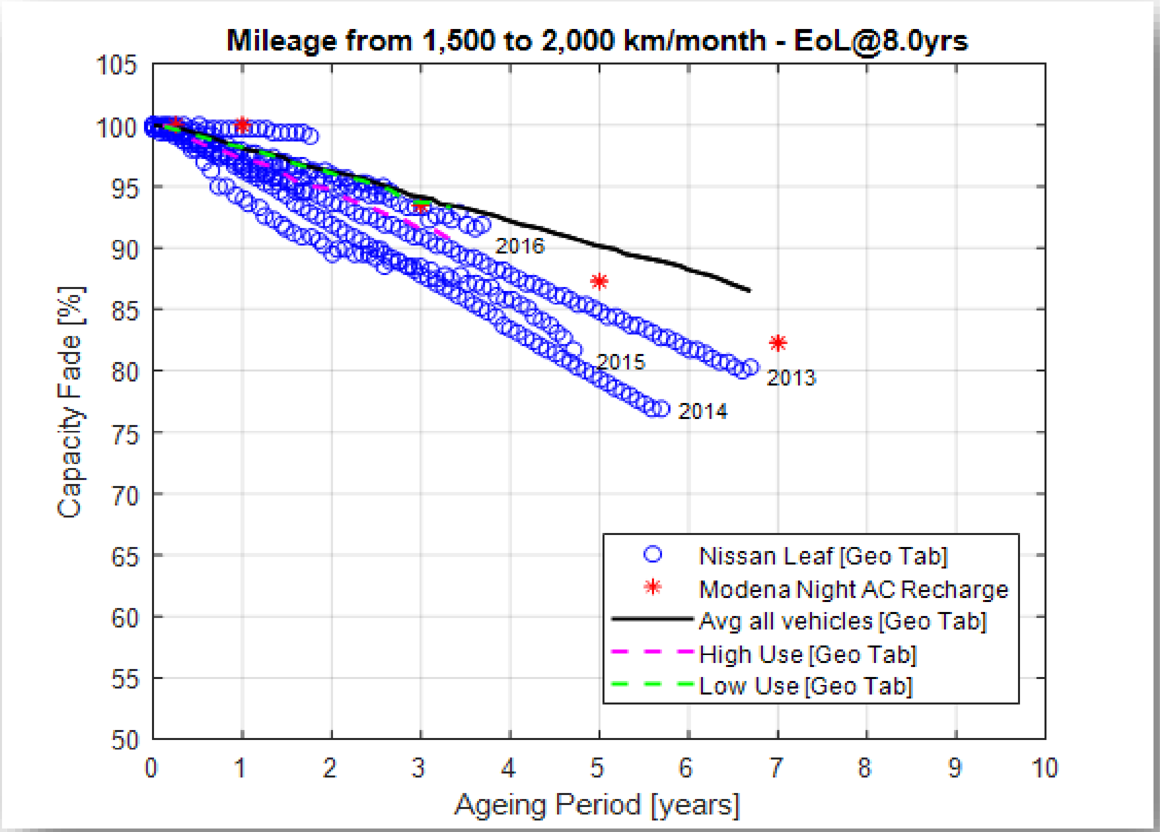
Comparing JRC TEMA ageing prediction with additional data from the field

- *What can 6,000 electric vehicles tell us about EV battery health?* Published on December 13, 2019 in Electric Vehicles by Charlotte Argue (https://www.geotab.com/)
- Compare the average battery degradation for different vehicle makes and model years, analysing the battery health of 6,300 fleet and consumer EVs, representing 1.8 million days of data.
- From the telematics data processed, providing aggregated average degradation data for 21 distinct vehicle models, representing 64 makes, models, and years.
- The degradation data displayed are the average trend line from the data analysed.
- Additionally analyses of:
  - high vehicle use
  - extreme climates
  - charging type.

https://www.geotab.com/

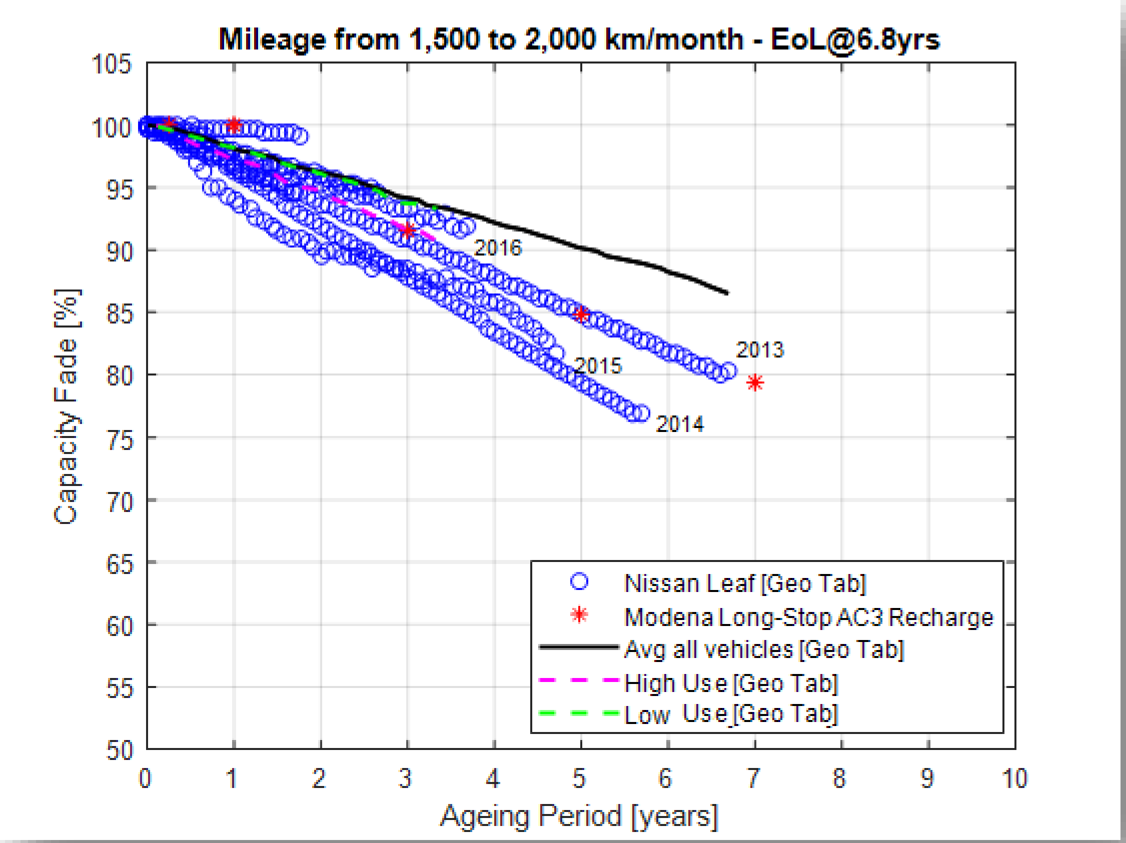
Comparing JRC TEMA ageing prediction with additional data from the field

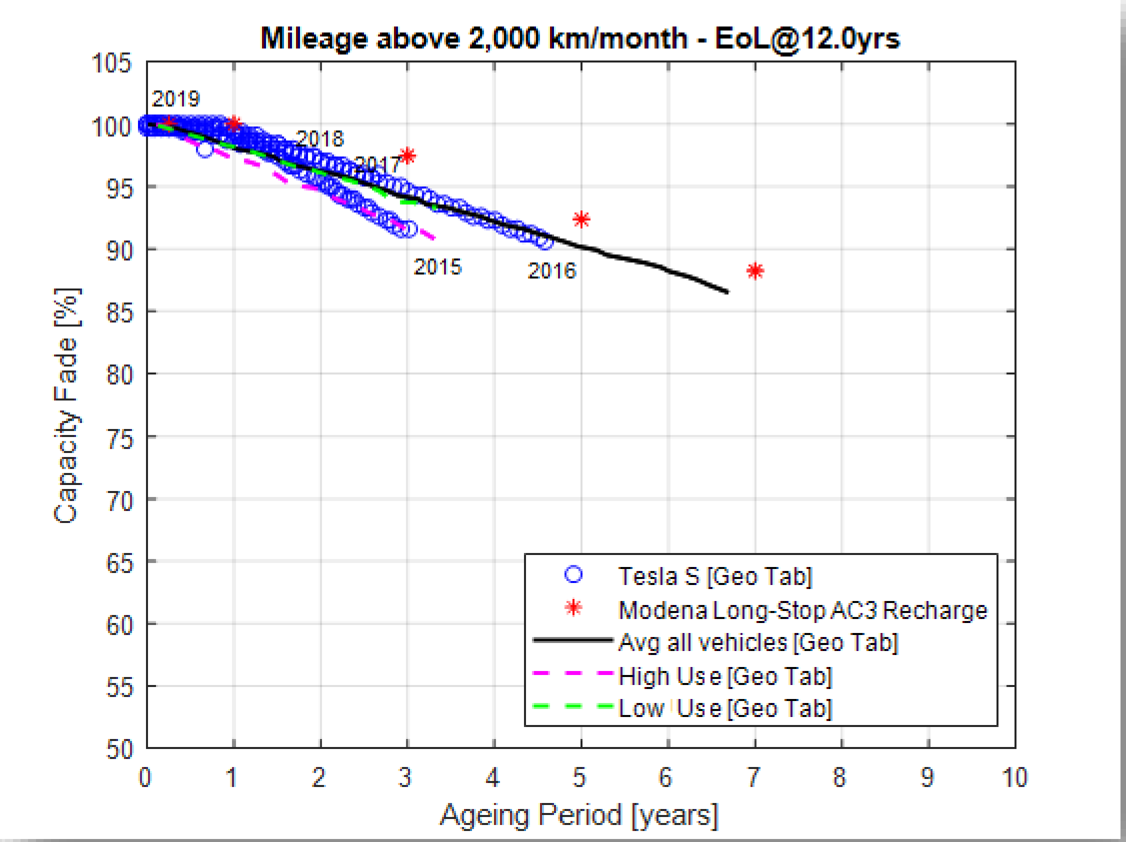




https://www.geotab.com/

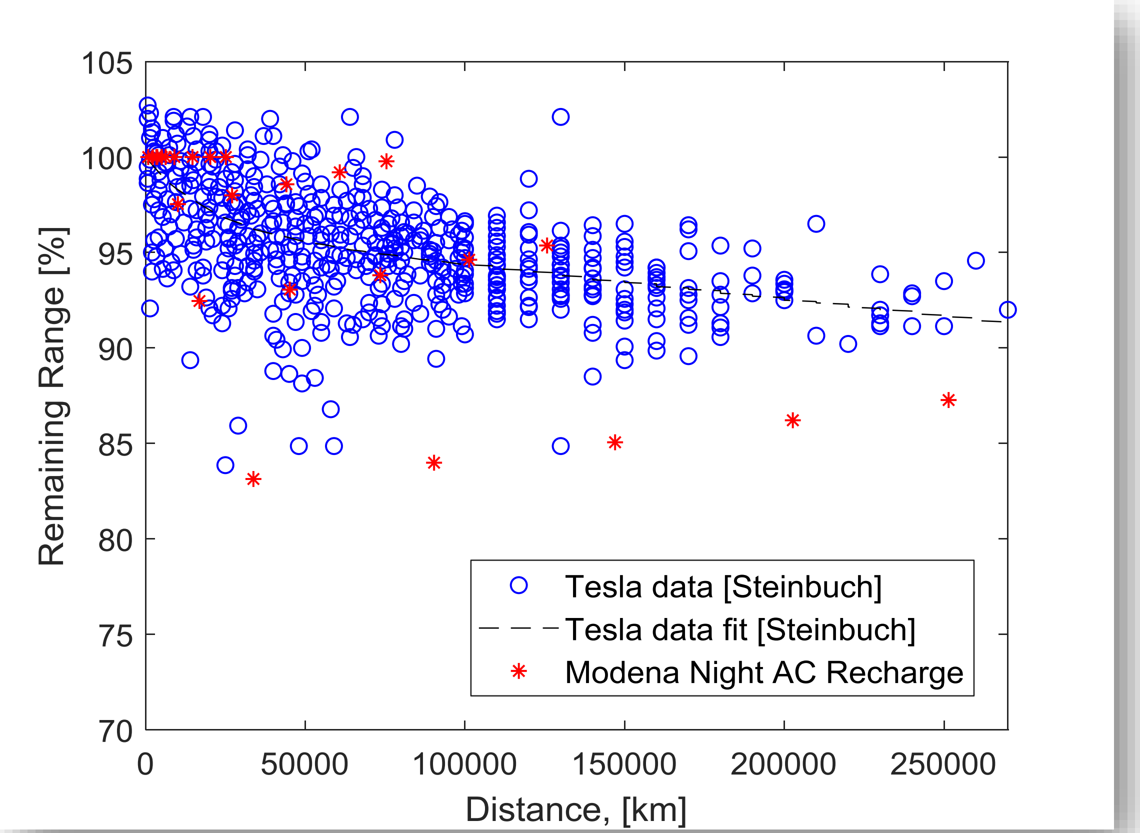
Comparing JRC TEMA ageing prediction with additional data from the field



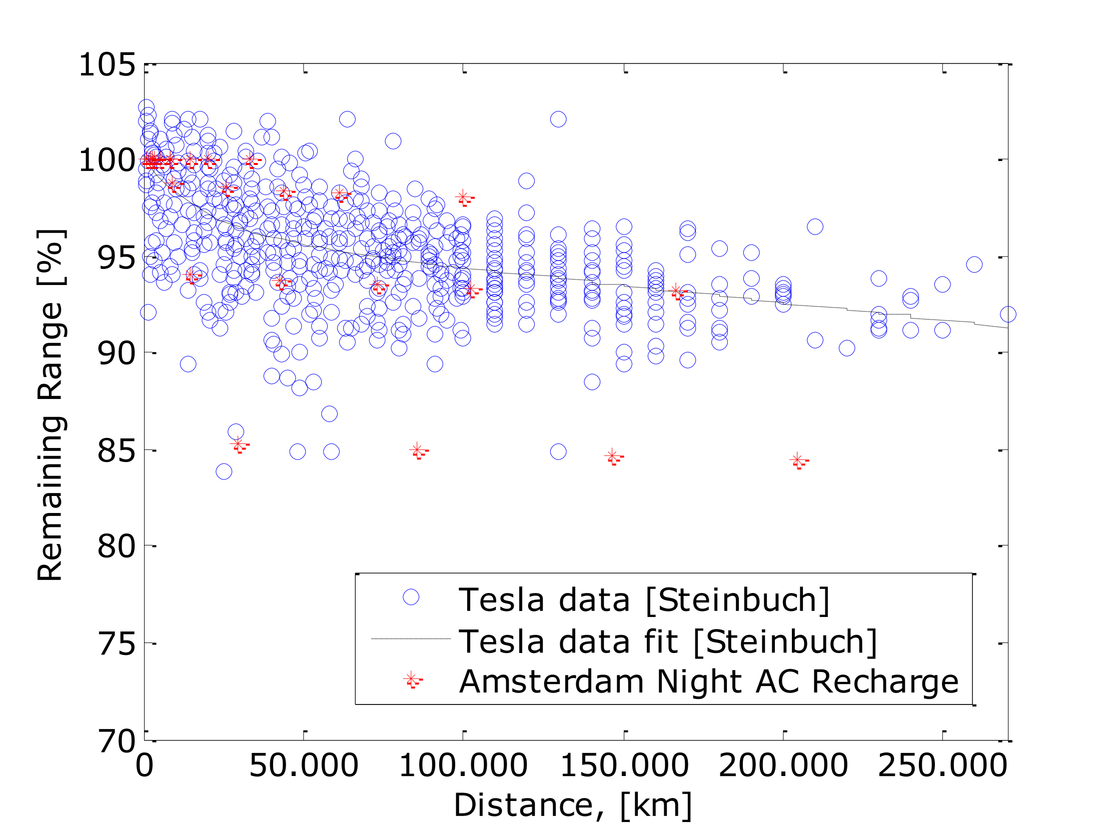


https://www.geotab.com/

EVE-30-12e.pdf & EVE-34-16e.pdf
Data comparison: Tesla data - #4 (NCM-LMO)



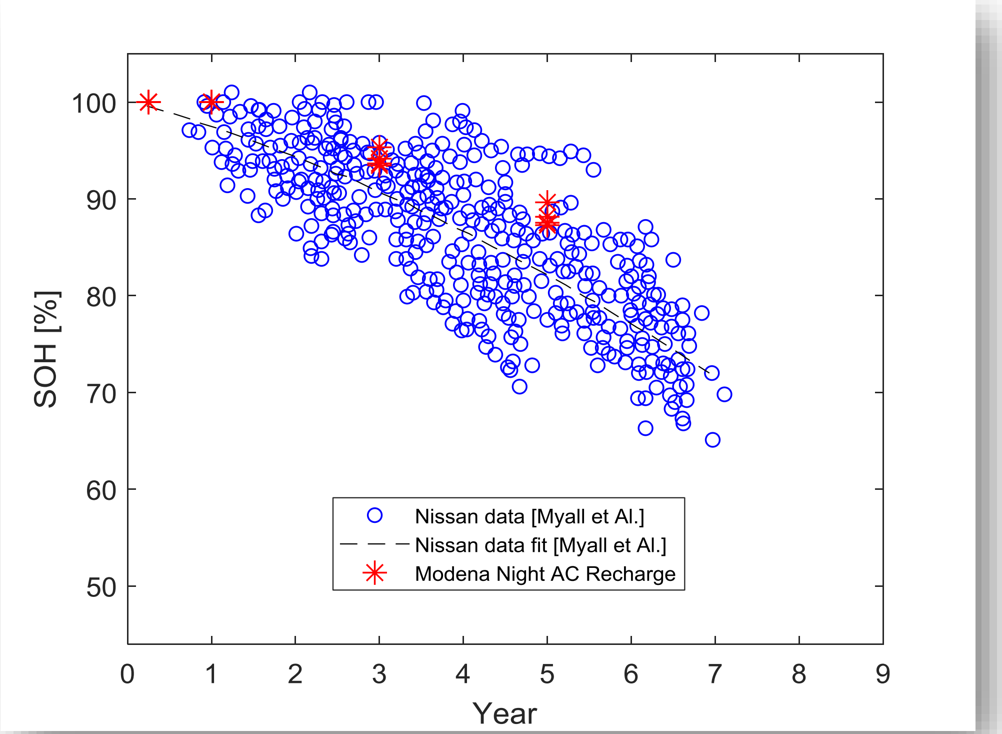
Night AC recharge – Modena Data



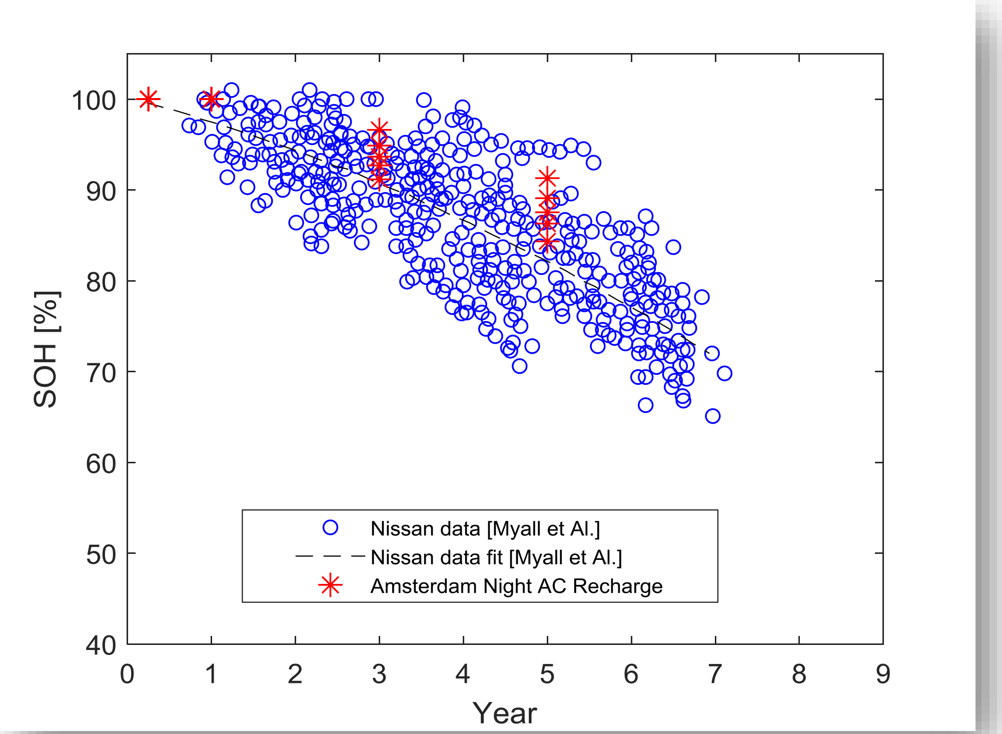
Night AC recharge – Amsterdam Data

*Technical University Eindhoven, May2018, https://steinbuch.wordpress.com/2015/01/24/tesla-model-s-battery-degradation-data

EVE-30-12e.pdf
Data comparison: Nissan Leaf data - #4(NCM-LMO)



Night AC recharge – Modena Data

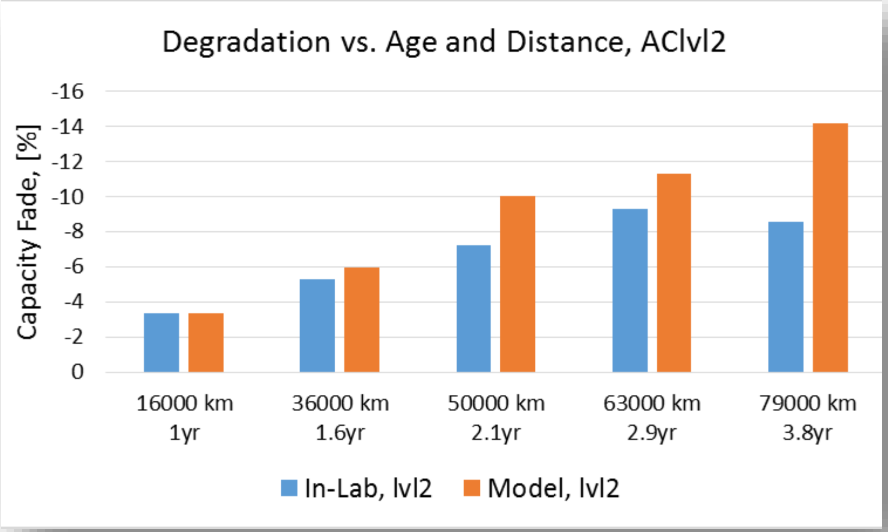


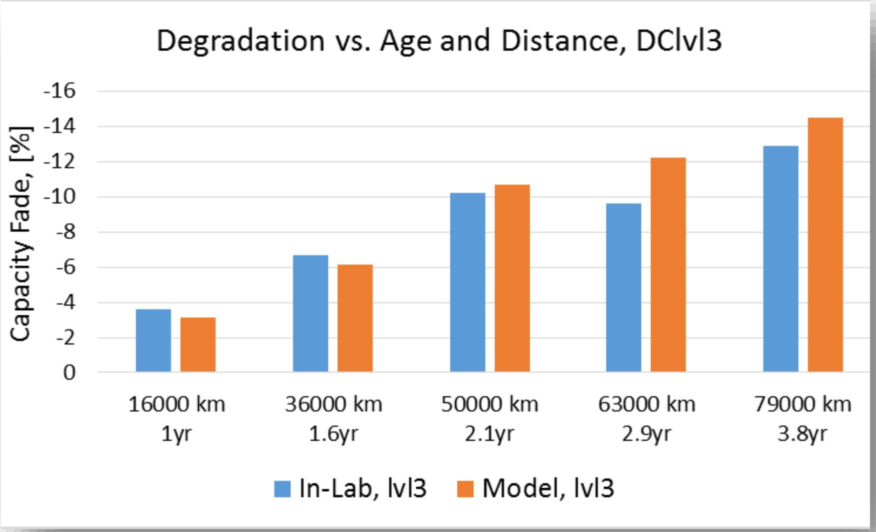
Night AC recharge – Amsterdam Data

#4 NCM-LMO cell assumed; it might differ from the battery chemistry of the 24kWh Nissan Leaf data

*Myall, Dima Ivanov, Walter Larason, Mark Nixon, Henrik Moller, Preprints, 2018, doi:10.20944/preprints201803.0122.v1

EVE-32-13e.pdf
Experimental data from Canada





In-vehicle validation of the model (assumptions):

- Uniform T, DoD, C-rate and Ah-throughput;
- T, DoD @ battery level;
- C-rate and Ah-throughput @ cell level;
- Qloss-total = Qloss-cal. + Qloss-cycle - Reserve(10%);
- NCM-LMO model (closer to real LEAF chemistry i.e. LiMn2O4 with LiNiO2)

  - 79,000 km driven in 3.8 years
  - two new comparisons at 63,000km and 79,000 km

*Aaron Loiselle-Lapointe, Samuel Pedroso

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Generalising JRC TEMA in-vehicle battery durability model: is it possible?

#1

Performance-based models

(validated on exp. at cell-level)

- Predefined calendar and cycling models (Model 1 to Model 5)
- Fitting equations and parameters for calendar and cycling ageing

#2

Vehicle reference architectures

(from cell-to-vehicle)

- Predefined reference architectures
- Customised: parameters (still to check this possibility)

#3

Real-world Driving data

- Predefined different EU duty cycle and recharging strategies
- Customised: average information (see table of inputs)

#4 Durability Scenarios

(Yrs and/or km to EoL)

- Predefined different vehicle technologies
- Predefined different recharging strategies

Hierarchical relation of the variables (tentative)

Level 1 (highest influence) →
- **Electrical architecture of the battery;**
- **Li-Ion chemistry;**
- **Driving pattern / mileage, i.e. *time, SOC, DOD, Ah, C-rate;***

Level 2 (high influence) →
- **Environment temperature for the calendar ageing (No active BMS)**

Level 3 (mid-to-low influence) →
- **Environment temperature on the cycling ageing if BMS active**

Is the phenomenon fully comprehended? NO → More efforts needed

Input/output of in-vehicle battery durability module of JRC TEMA platform

	Input to JRC TEMA
General parameters	• Age of the car since manufacture [yrs] • Run-in km • Vehicle technology (BEV, PHEV) • EoL threshold for capacity fade and power fade
Environmental parameters	• Ambient temperature max and min for each month of the year [°C]
Duty cycle parameters	• Average number of trips per month • Average driven distance [km] • Average driving time [h] • Average driving speed [km/h] • Average energy consumption [Wh/km] • Average resting time without charging [h] • Average parking time [sec]
Charging data	• Average recharging time [h] • Recharging power [kW] • Charging mode/level • Average number of recharge per month
Battery parameters	• Battery chemistry • Battery architecture (no. of modules, no. of cells, cell voltage, cell current, series/parallel connection i.e. 48S-2P-2S etc.) • Reference battery voltage [V] • Battery capacity [Wh] • Battery reserve [%] • Average weighted battery temperature [°C] • Battery temperature min and max (BMS) [°C] • Average battery SoC min driving [%] • Average battery Delta SoC during charging [%] • Average battery SoC parking no charging [%]

HV battery chemistry	**Output from JRC TEMA**			
	Capacity fade		**Power fade**	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + Spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Thank you for the attention

Q&A

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Implementation of the performance based models into JRC TEMA (assumptions, 2/2)

The models have been implemented by adopting the following assumptions:

- the calendar and cycle capacity fades are calculated at cell level (uniform ageing assumption);
- the model assumes average quantities in the reference period per each vehicle for DOD, C-rate, Ah-throughput and temperature;
- DOD and temperature are assumed equal to the battery values, consistently with the uniform fade assumption, whilst the C-rate and Ah-throughput are scaled from the battery level down to the cell;
- the battery temperature is regulated by the BMS between 22 °C and 27 °C during the driving and recharging phases (cycle capacity fade modelling), whilst it assumes the ambient temperature in the parking phase (calendar capacity fade modelling);
- The model capacity fade is calculated at the net of the capacity fade reserve. i.e.:

  Qloss-total = Qloss-calendar + Qloss-cycle - Reserve

- 5 recharge strategies adopted:
  - ✓Str. 1 = Long Stop Random AC;
  - ✓Str. 2 = Short-Stop Random DC;
  - ✓Str. 3 = Night AC - Str. 4 = Smart AC;
  - ✓Str. 5 = Long-Stop AC 3-phases;