In-vehicle battery durability for electrified vehicles
PART A: Verification of monitors
Option B
Web meeting

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26th May 2021
Verifying the method Option B for the battery monitors

• For evaluating the SOCR/SOCE monitors normalised values shall be calculated:

\[ x_i = \frac{SOC_{\text{read},i}}{SOC_{\text{measured},i}} \quad \text{or} \quad x_i = SOC_{\text{read},i} - SOC_{\text{measured},i} \]

• Where: \( SOC_{\text{read},i} \) is the SOCR/SOCE monitor read from the vehicle \( i \)

\( SOC_{\text{measured},i} \) is the measured SOCR/SOCE monitor of the vehicle \( i \)

• For the total number of \( N \) tests and the normalised values of the tested vehicles, \( x_1, x_2, \ldots, x_N \), the average \( X_{\text{tests}} \) and the standard deviation \( s \) shall be determined:

\[ X_{\text{tests}} = \frac{x_1 + x_2 + x_3 + \ldots + x_N}{N} \]

\[ s = \sqrt{ \frac{(x_1 - X_{\text{tests}})^2 + (x_2 - X_{\text{tests}})^2 + \ldots + (x_N - X_{\text{tests}})^2}{N - 1} } \]

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Summary of the methodology

- The proposed testing method follows the same steps of CO$_2$ CoP testing:
  - Boundaries around a theoretical mean
    \[ m(i) = A - t_{N-1,CL} \frac{s(i)}{\sqrt{N}} \]
    \[ lb(i) = m(i) - t_{i-1,CL} \frac{s(i)}{\sqrt{i}} = A - \left( \frac{t_{i-1,CL(i)}}{\sqrt{i}} + \frac{t_{N-1,CL(i)}}{\sqrt{N}} \right) \times s(i) \]
    \[ ub(i) = m(i) + t_{i-1,CL} \frac{s(i)}{\sqrt{i}} = A + \left( \frac{t_{i-1,CL(i)}}{\sqrt{i}} - \frac{t_{N-1,CL(i)}}{\sqrt{N}} \right) \times s(i) \]
  - If \( Xtests \leq A - (t_{P1,N} + t_{P2,N}) \times s \) the family gets a pass
  - If \( Xtests > A + (t_{F1,N} - t_{F2,N}) \times s \) the family gets a fail
  - Else it is required to measure another vehicle, increase \( N \) by 1, recalculate the mean and the standard deviation and repeat until a decision of pass or fail is reached

- Fail boundary with constant confidence level (same as CO$_2$ CoP)
  \[ cL_{up} = 0.95; \]
- Pass boundary with decreasing confidence level (same as CO$_2$ CoP) while \( i \) increases
  \[ cL_{lo} = [0.95 \ 0.945 \ 0.935 \ 0.92 \ 0.9 \ 0.875 \ 0.845 \ 0.81 \ 0.77 \ 0.725 \ 0.675 \ 0.62 \ 0.56 \ 0.5]; \]

Confidence level decrement increasing proportionally with sample size

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Visualisation of the proposed method

Acceptance and rejection boundaries ($\sigma=0.02, A=1.00, N=16$)

Acceptance boundaries

Sample size

$A(m(i) = A - t_{N-1,cL} \times s(i) / \sqrt{N})$

$cL_{lo} = [0.95, 0.945, 0.935, 0.92, 0.9, 0.875, 0.845, 0.81, 0.77, 0.725, 0.675, 0.62, 0.56, 0.5]$; growing difference for bigger sample sizes

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Ideal case

Option B Ideal Case

Limited sample size to take decision

NO false fails

Cumulative Pass

Sample Size

NO false passes

(SOC(read) = (SOC(measured))

(SOC(read) = (SOC(measured)) + 5

(SOC(read) = (SOC(measured)) - 5

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Ratio vs Difference

$\text{soc}_{\text{read}}$ shifted above or below the mean value by 5%

**Option B** Ratio (A=1.05) and Difference (A=5%) $\sigma=1.56$

- Ratio method more stringent for same A value

Delayed passes

$\text{SOC}_{\text{read}} = \text{SOC}_{\text{measured}}$ (RATIO)

$\text{SOC}_{\text{read}} = \text{SOC}_{\text{measured}} + 5$ (RATIO)

$\text{SOC}_{\text{read}} = \text{SOC}_{\text{measured}} - 5$ (RATIO)

$\text{SOC}_{\text{read}} = \text{SOC}_{\text{measured}}$ (DIFFERENCE)

$\text{SOC}_{\text{read}} = \text{SOC}_{\text{measured}} + 5$ (DIFFERENCE)

$\text{SOC}_{\text{read}} = \text{SOC}_{\text{measured}} - 5$ (DIFFERENCE)
Bimodal populations $soc_{read}$ shifted above or below the mean value by 5%

Option B Difference A=5% standard cL - Bimodal and Normal Population ($\sigma=1.56$)

Randomly generated bimodal distribution ($\mu=78; \sigma=1$ and $\mu=82; \sigma=1.5$)

Bimodal distribution leads to acceptance with higher number of samples

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Option B: Bimodal vs Normal Population ($\sigma = 1.56$) - Difference A=5%  Ratio A=1.05

Acceptance with higher number of samples:

- Bimodal distribution
- Ratio method

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Increased dispersion of data (higher $\sigma$) or lost of accuracy:

- socread shifted above or below the mean value by 5%

- Delayed passes

- Increased dispersion leads to acceptance with higher number of samples

- Possibility to read data as data at 5y and 8y

Option B  **Difference A=5%** standard cL - Influence of $\sigma$

- $\{\text{SOCRead}\} = \{\text{SOCEmeasured}\} (\sigma=2.5)$
- $\{\text{SOCRead}\} = \{\text{SOCEmeasured}\} + 5 (\sigma=2.5)$
- $\{\text{SOCRead}\} = \{\text{SOCEmeasured}\} - 5 (\sigma=2.5)$
- $\{\text{SOCRead}\} = \{\text{SOCEmeasured}\} (\sigma=1.56)$
- $\{\text{SOCRead}\} = \{\text{SOCEmeasured}\} + 5 (\sigma=1.56)$
- $\{\text{SOCRead}\} = \{\text{SOCEmeasured}\} - 5 (\sigma=1.56)$
Standard cL and modified cL

$soc_{\text{read}}$ shifted above or below the mean value by 5%

- Higher pass rates for lower sample sizes with decreased confidence level
Combining modified $cL$ and increased $\sigma \text{soc}_{\text{read}}$ shifted above or below the mean value by 5%
Testing statistics with different distribution shape

- JRC TEMA simulated capacity retention data at 5y and 8y (ref. EVE-41-03e)

### 5y aged BEV1 vehicles – strategy 1 and 2

<table>
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<th>min</th>
<th>1st Qu</th>
<th>median</th>
<th>mean</th>
<th>3rd Qu</th>
<th>max</th>
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Normal vs JRC TEMA

soc_{read} shifted above or below the mean value by 5%

Delay passes

Option B Difference A=5% (Normal $\sigma=1.56$ and JRC TEMA 5y)

- Statistics from JRC TEMA more affected by higher area of the tails
- Acceptance with higher number of samples

Cumulative Pass

Sample Size

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Thank you

Q&A

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Comparing Options A1 and B

Option A1, B Difference

Cumulative Pass

Sample Size

3 4 5 6 7 8 9 10 11 12 13 14 15 16

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Comparing Options A2 and B

Option A2, B Difference

- \( \{\text{SOCEread}\} = \{\text{SOCEmeasured}\} - 5 \)
- \( \{\text{SOCEread}\} = \{\text{SOCEmeasured}\} \)
- \( \{\text{SOCEread}\} = \{\text{SOCEmeasured}\} + 5 \) (Opt.B Difference A=7%)
- \( \{\text{SOCEread}\} = \{\text{SOCEmeasured}\} + 5 \) (Opt.A1)
- "\( \{\text{SOCEread}\} = \{\text{SOCEmeasured}\} + 5 \) (Opt.B Difference A=5%)"
Option B Difference $A=1\%$

$soc_{\text{read}}$ shifted above or below the mean value by 5%
Randomly generated bimodal distribution 10’000 values as combination of two normal distributions

\( \mu=78; \sigma=1 \) and \( \mu=82; \sigma=1.5 \)

Data = [normrnd(78,1,[5000,1]) ; normrnd(82,1.5,[5000,1])];

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<tr>
<th>min</th>
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<th>median</th>
<th>mean</th>
<th>3rd Qu</th>
<th>max</th>
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<tbody>
<tr>
<td>74.492</td>
<td>78.016</td>
<td>79.599</td>
<td>79.989</td>
<td>81.950</td>
<td>87.295</td>
<td>2.350</td>
</tr>
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</table>
Bimodal population same results as more dispersed distribution $soc_{\text{read}}$ shifted above or below the mean value by 5% 

Option B: Difference A=5% standard cL - Bimodal and Normal Population ($\sigma=2.5$)

Delayed passes
Changing Confidence Level

Acceptance and rejection boundaries (\(\sigma=0.02, A=1.00, N=16\))

- \(\text{ub}\)
- \(\text{lb fixed cL}\)
- \(\text{lb varying cL}\)
- \(\text{lb (modified cL)}\)
- \(A\)

\[m(i) = A - t_{N-1,cL} \cdot s(i) / \sqrt{N}\]

- \(cL_{lo} = [0.95 \ 0.945 \ 0.935 \ 0.92 \ 0.91 \ 0.875 \ 0.845 \ 0.81 \ 0.77 \ 0.725 \ 0.675 \ 0.62 \ 0.56 \ 0.5]\): growing difference for bigger sample sizes
- \(cL_{lo} = [0.950 \ 0.915 \ 0.881 \ 0.846 \ 0.812 \ 0.777 \ 0.742 \ 0.708 \ 0.673 \ 0.638 \ 0.604 \ 0.569 \ 0.535 \ 0.500]\): constant difference
Ratio A = 1.05 Increased $\sigma$

$\text{soc}_{\text{read}}$ shifted above or below the mean value by 5%

**Option B**  
Ratio A = 1.05  
standard cL - Influence of $\sigma$

In Figure 3 to 11, the impact of increased dispersion ($\sigma$) is shown. The cumulative pass rate is plotted against the sample size. The dotted line represents $\sigma = 1.56$ and the solid line $\sigma = 2.5$. The figure illustrates that increased dispersion leads to an increase in the number of samples required for acceptance. 

- Increased dispersion leads to acceptance with a higher number of samples.