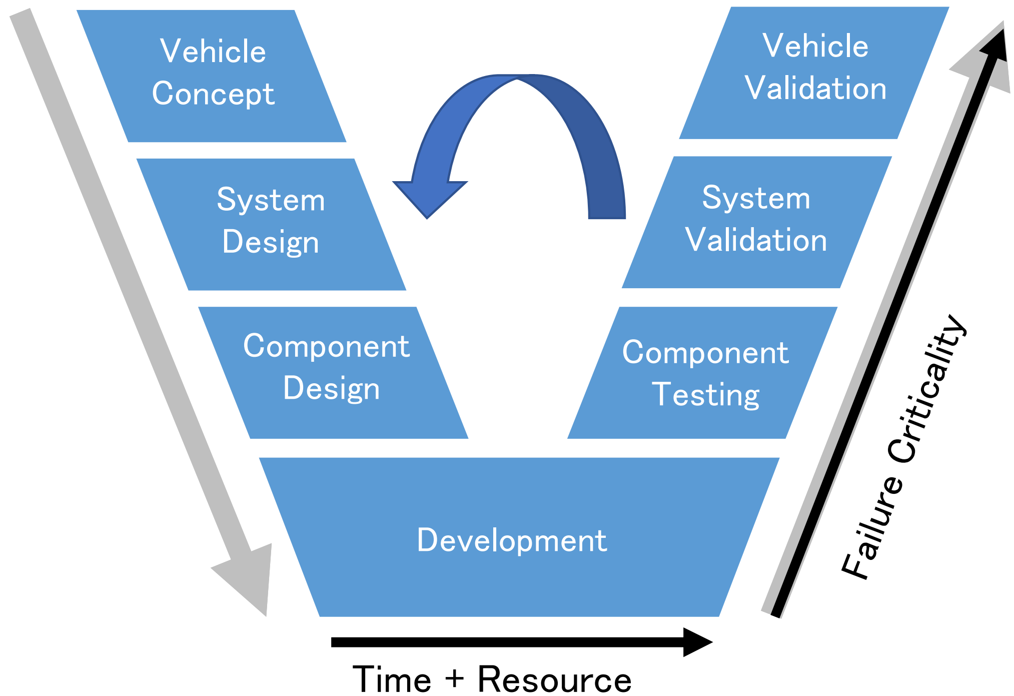
# Battery Modelling for Frontloading the Issues in EV/HEV Development

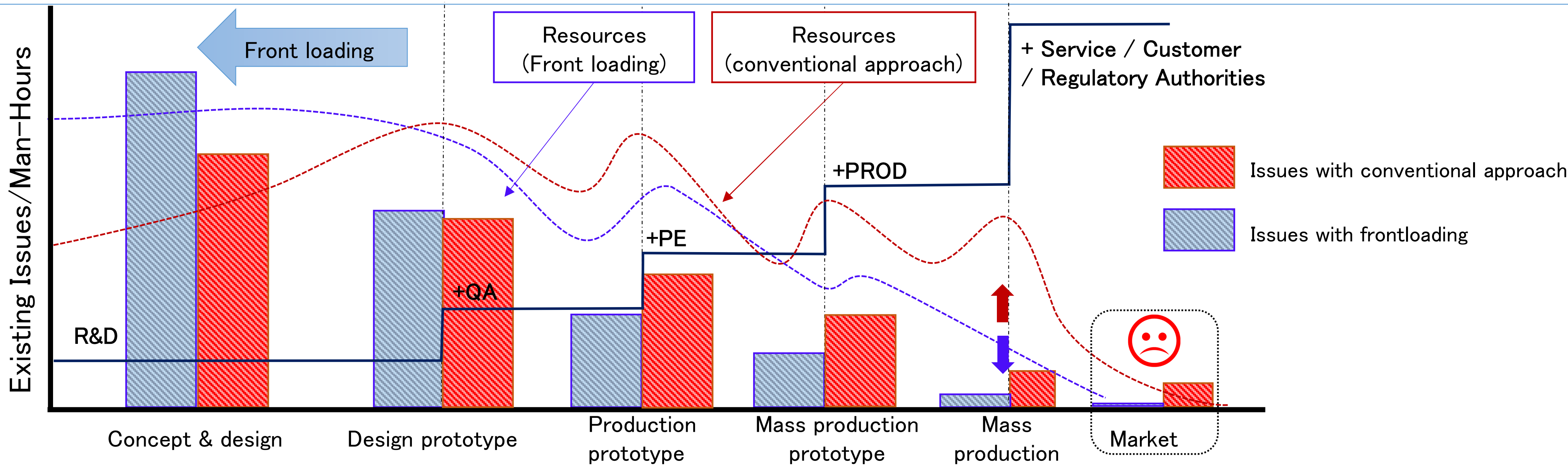
Vikram Singh | Amit Kumar
Advanced Battery dev.
Maruti Suzuki India limited

# Conventional Development Process

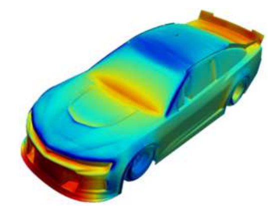



it is better to ‘Fail Early’ to be able to take counter-measures effectively

# Front Loading: Optimize Critical Resources




## Key enablers of front loading



- ❑ Design Reviews
- ❑ Rapid Prototyping
- ❑ Desktop Tools
- ❑ Simulation

**Simulation and virtual validation are key enablers of front loading**

# Challenges in Battery design for Indian Conditions

## Varied Climatic Conditions

## Varied Terrains

**Indian subcontinent poses its unique challenges on battery design & testing.**

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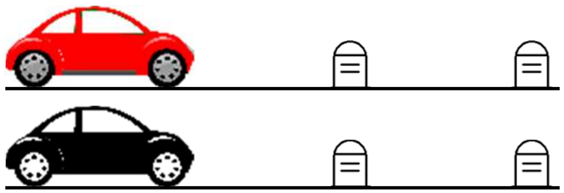
# Testing & Validation in Battery Development

## Physical testing



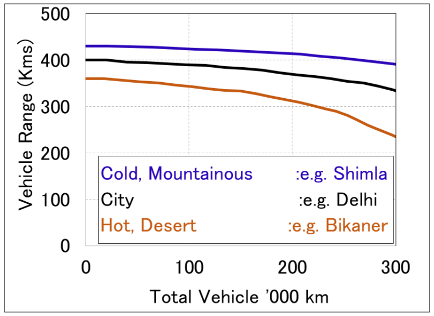
- 160,000 km x 25? vehicles
- 18 months
- 25 MWh x 25? vehicles

## Electrical testing

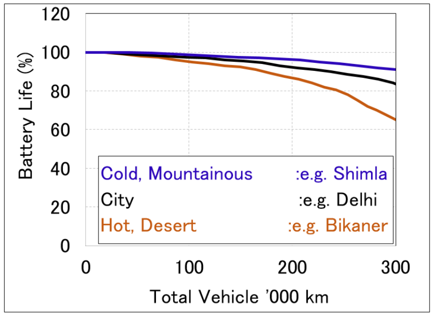
- Vehicle tests @ 5000 km

## Thermal testing

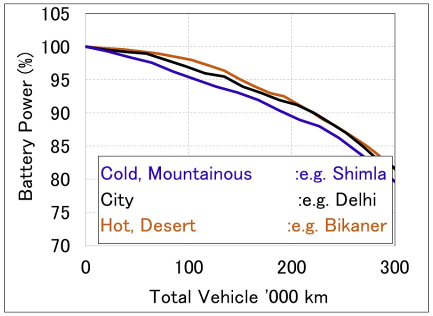
- Climate tests




Range



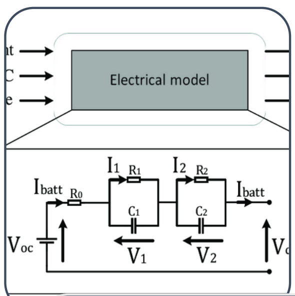

Life




Power

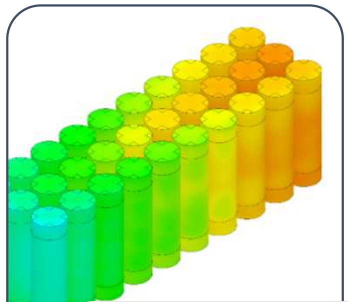
**Extensive testing is required to validate battery for Indian conditions**

# Simulation In Battery development




## Electrical

- Power- Life
- Electrical safety limit



## Thermal

- BTMS Design
- Thermal Runaway Safety

## Structural

- Packaging and layout
- Mountings
- Crash safety

Electrical simulation is crucial for design of any Battery

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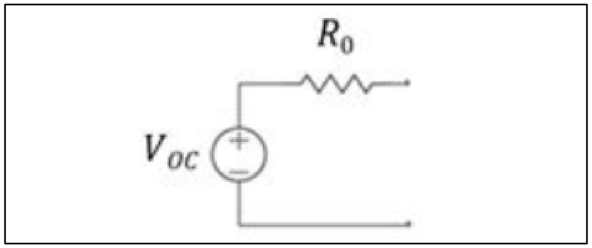
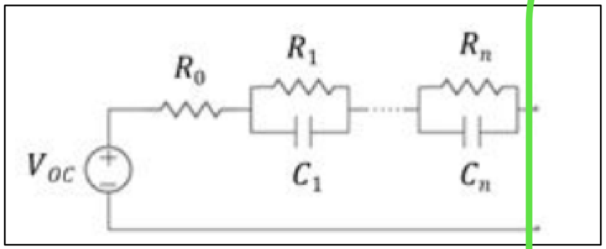
# Battery Modelling approach

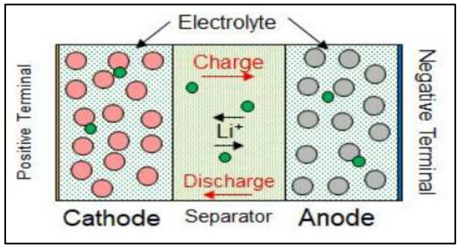
Lower Model Fidelity

Battery Modelling Approach

High Model Fidelity




**Resistive Models**

- Perfect for steady-state simulations
- Easiest to calibrate models (discharge/charge profiles)

**Thevenin Models**

- Better for dynamic simulations
- Calibrated by matching voltage response to current pulses

**Electrochemical Models**

- Physics-based modelling behaviour of cell
- Calibrated with cell design information & matching results

Electrical-Equivalent Models

**Pros**

- Easy to build, calibrate
- Good Voltage, Current, SOC
- Good Heat Rate

**Cons**

- Can't reliably use outside calibrated temperature
- **Empirical Aging models**
- Change in cell design requires re-calibration
- Requires extensive Testing

Electrochemical Models

**Pros**

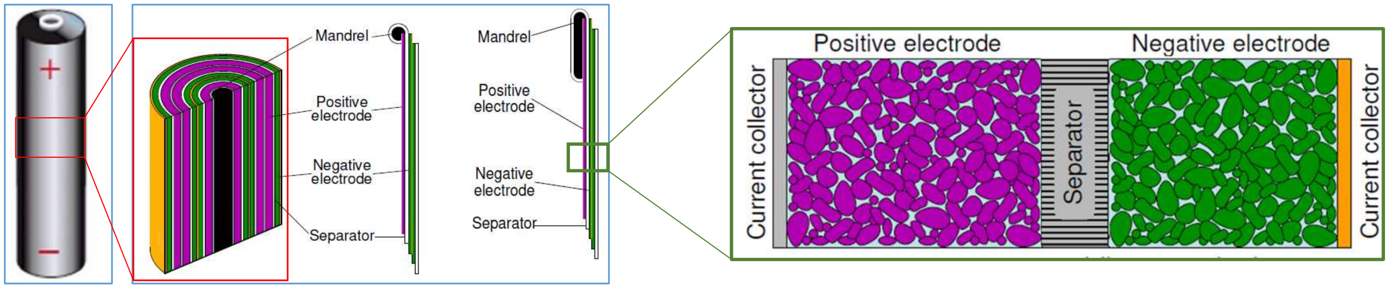
- Use outside calibrated temperature range
- **Physics-based aging models**
- Easily iterate on cell design

**Cons**

- Complex to build & calibrate
- Less accurate voltage, current, heat rate

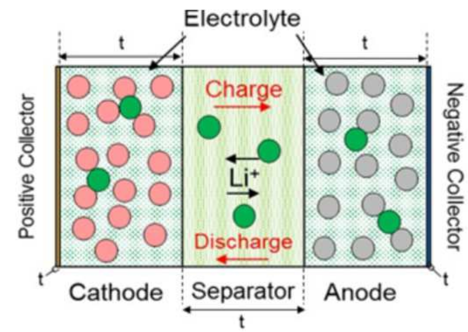
**Electrochemical modelling paves the way for holistic Battery Simulation**

# Electrochemical cell composition



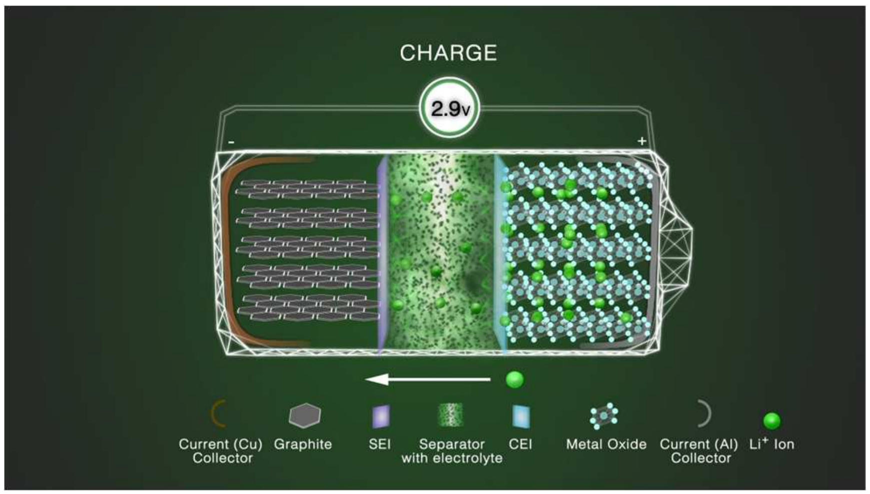

Cylindrical cell

Prismatic cell



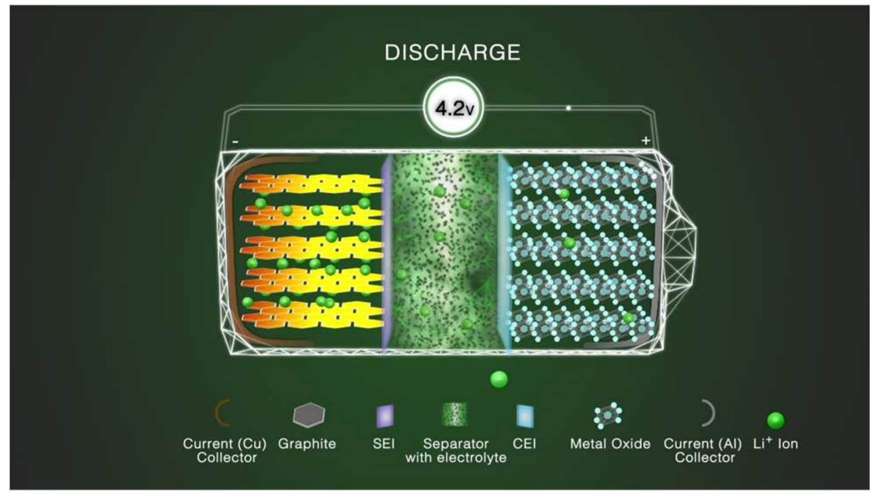

## While the battery is charging

Lithium-ions ($Li^+$) flow from the cathode to the anode.




## While the battery is in use

Lithium-ions ($Li^+$ )flow from the anode to the cathode.

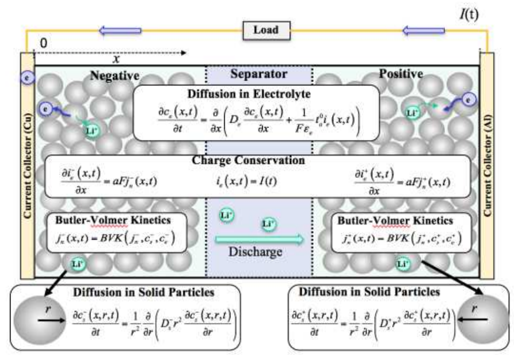


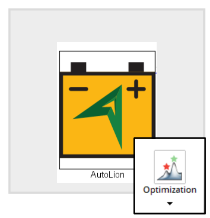

**GT AutoLion models cell's internal reactions.**

# Electro-chem. Battery modelling

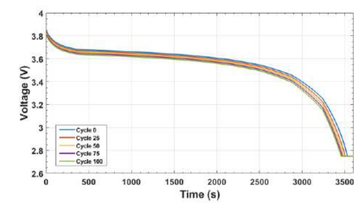
**Input** → **Model** → **Output**

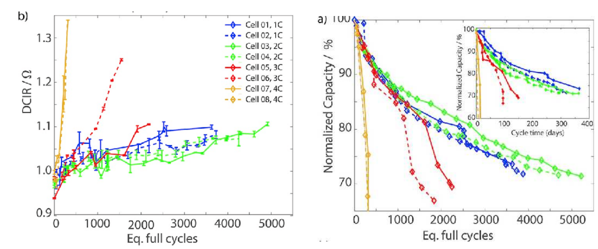
| Cell Data-sheet | Cycle Life | Calendar Life |
|---|---|---|
| Internal Data | Electrode, Separator Thickness | Active material Size |
| Test Data | CCV @ C/20 | CCV @ 1C, 2C, 3C |




An inbuilt optimizer is used to estimate the cell parameters using the input data.

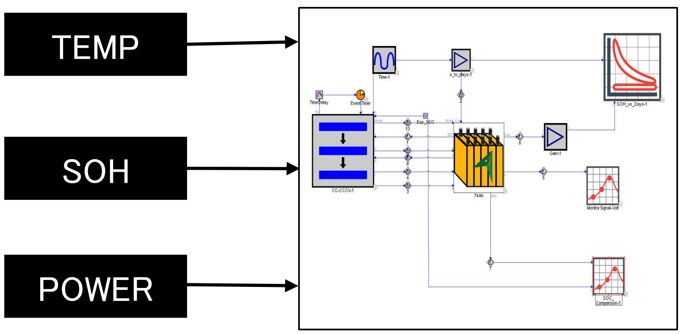



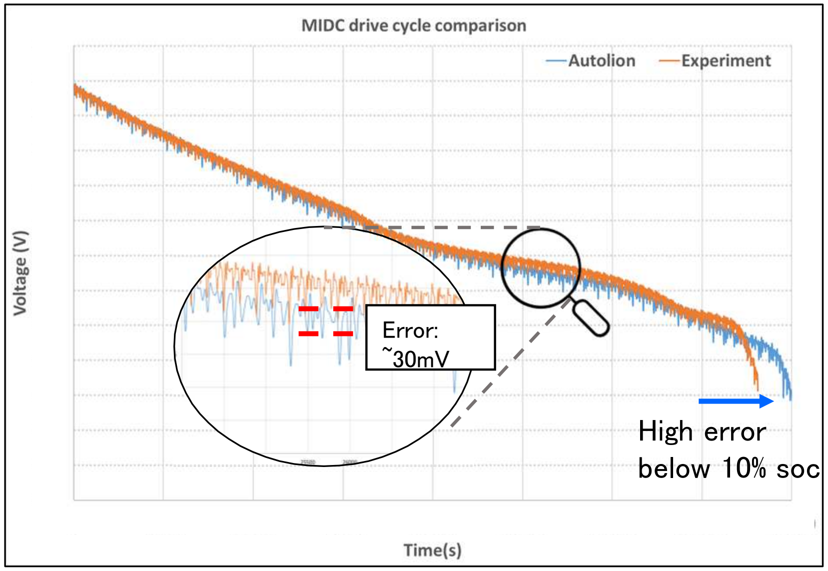




**Cell test data is used to find cell internal data.**

# Cell Voltage Characteristics Validation

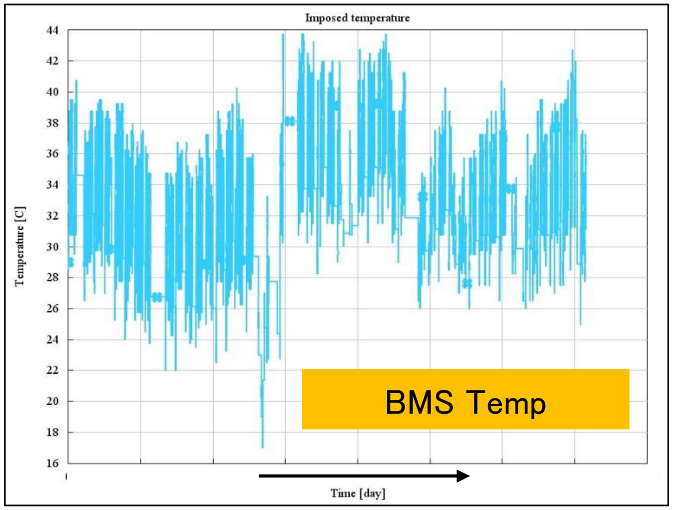
- A comparison between simulated and Actual data was done for several drive cycles
- Maximum error of 30 mV was observed.
- Benefits
  - The voltage  can be simulated for any SOH
  - Saves physical ageing process
  - Ables End of Life calibration at very early stage

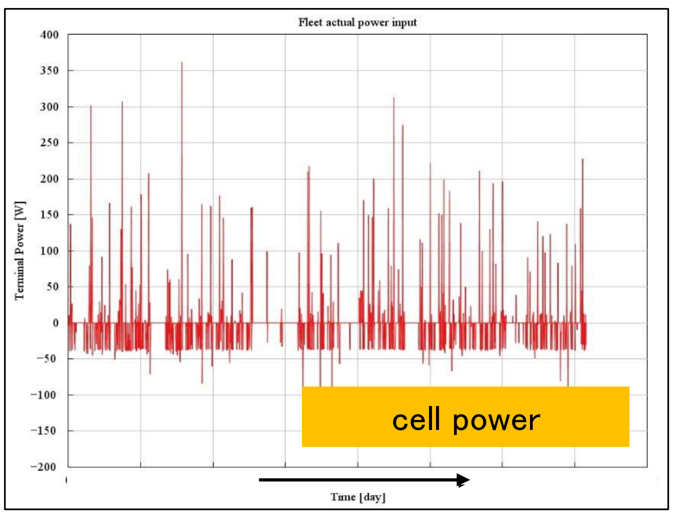


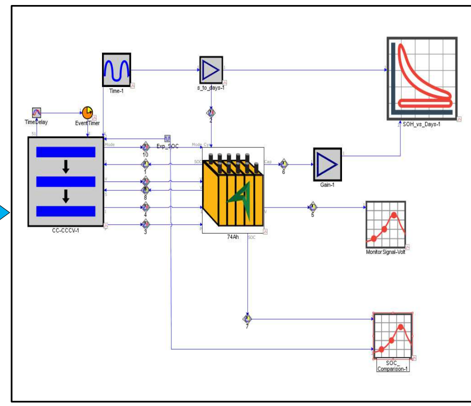

**Drive cycle voltage simulation is used for model validation before ageing simulation**

# Battery capacity degradation simulation

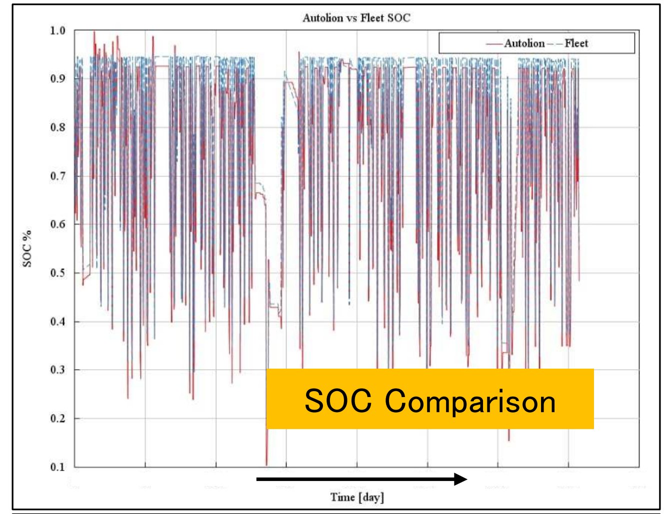


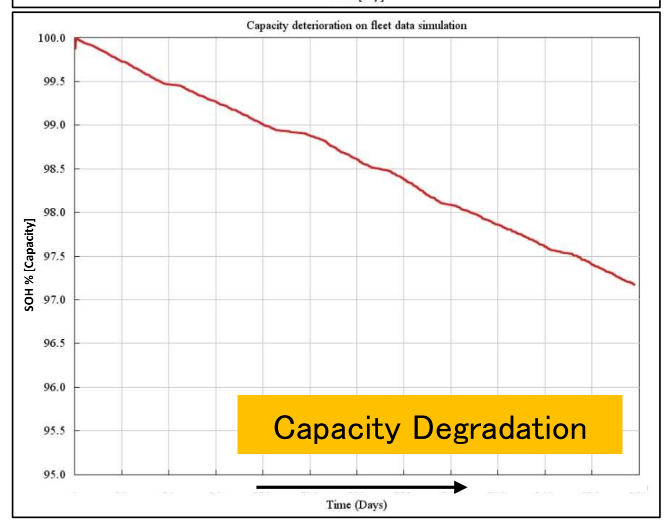




Actual vehicle data (power per cell & BMS average temperature) for 358 days is given as input for the simulation to check battery degradation.



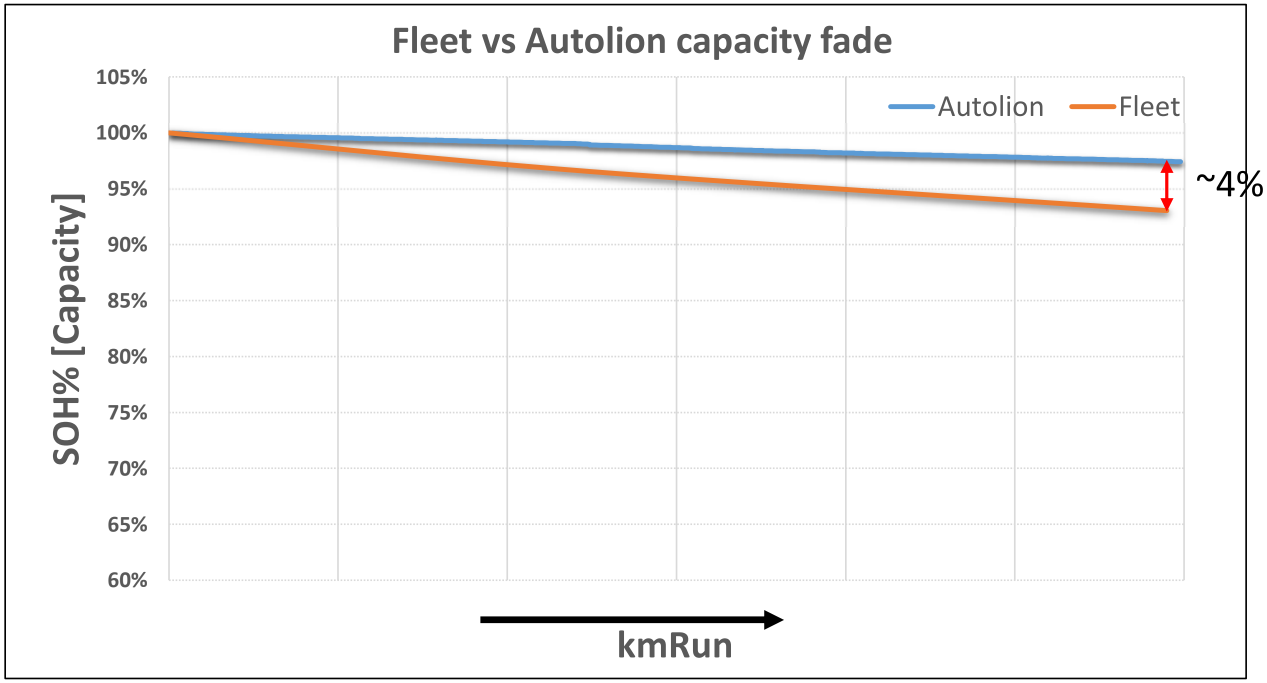
The comparison of Model SOC with Fleet SOC validates that the input and initial parameters to the model are correctly aligned. Further simulating for 358 days shows the Capacity degradation of the cell.



# Cell degradation based on actual vehicle simulation

- Simulation was performed by loading the cell with actual power requirement from the vehicle at given temperature to see the capacity fade.
- Cell loading data combines both the calendar aging as well as cycle aging so the results can be compared with real world scenario.
- We compared actual cell degradation with modelled cell.

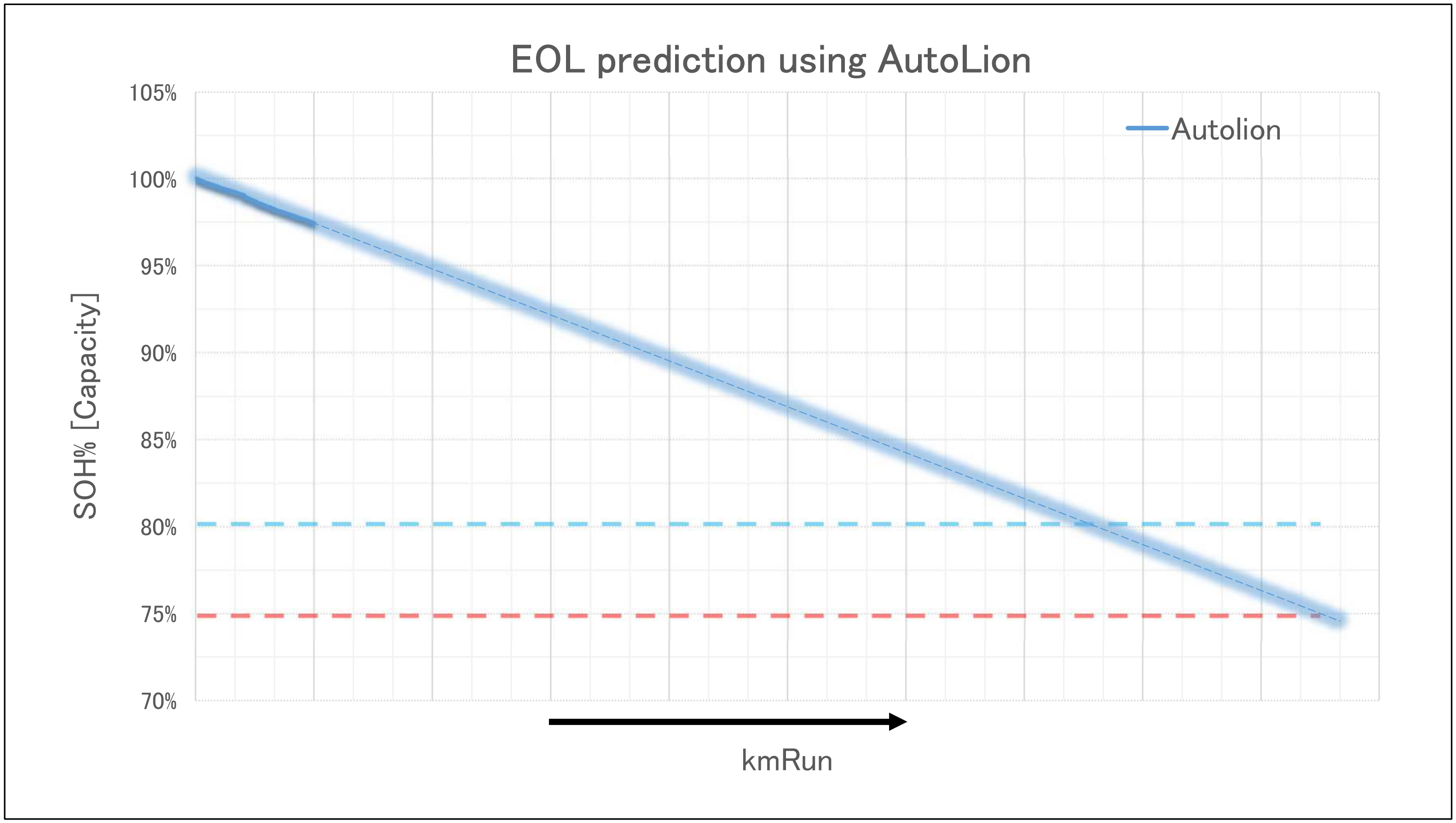



**Reason of error could be:**

- Unavailability of cell internal data (Thickness and particle size of Cathode/Anode/Separator).
- Compromised model training due to limited period of trial license.
- Averaged data for cell loading taken for the fleet actual battery power.

**Battery simulation result comparison with actual data.**

# End of life (EOL) prediction

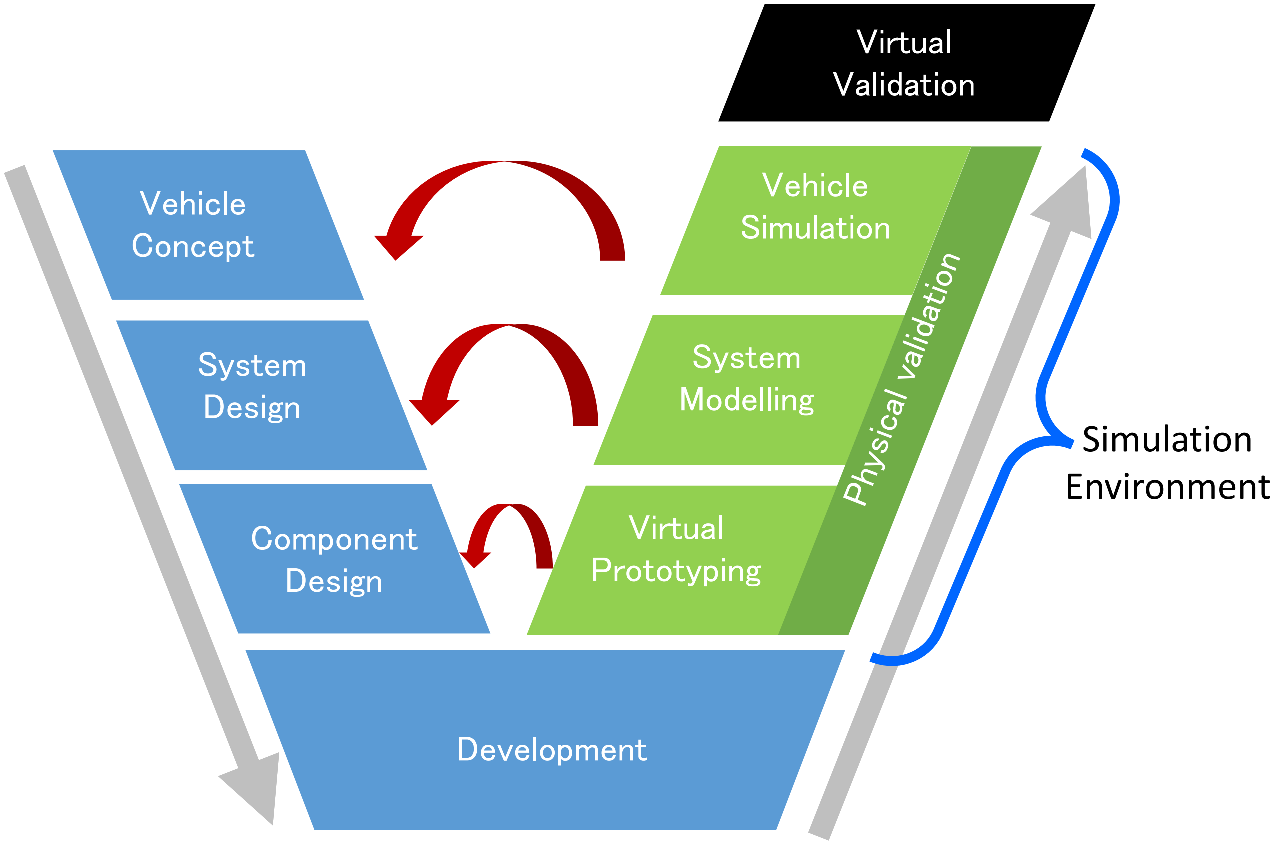



**Battery pack EOL and warranty estimation can be done for new product.**

# Conclusion

- An electro-Chem. Model was made with Cell Datasheet & basic test data.
- A successful simulation of battery data (Performance and health) was done and same was validated with actual data logged during fleet
- Even without cell internal data capacity was estimated
- This enables us to emulate and validate battery performance in real test environment (Shimla ,Chennai, Mumbai, Bikaner) much before any protype of the vehicle has been made.
- Help calibrate BMS for any stage of battery life
- It helped us to estimate warranty.
- Enables us to course correct our battery spec in very early design and development stage.
- Saves cost & Time.

# Virtual-V




- Reduced effort
- Maximize use cases
- Faster development
- Front load the issues
- Reduce development time

**The age of virtual proving grounds**


"The Best way to Predict the Future is to Design it"
-Buckminster Fuller
"The Best way to Design the Future is to "Predict" it"
Thank You