Unlock next generation of high-performance battery systems

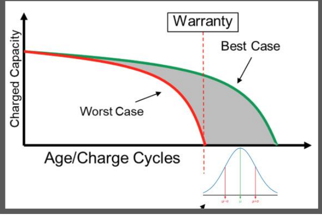
Electric Vehicle BMS: Establish a game-changing approach different from todays data driven single-technique

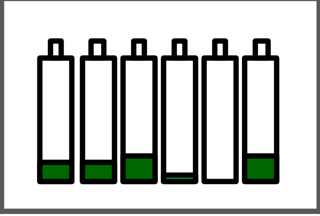
Common limitations today

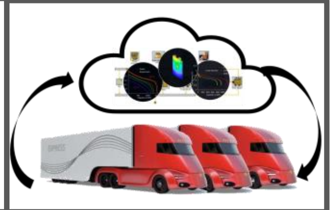
- The approach is heavily relying on data driven insights
- Large part of the system development is based on indications gained from cell tests and isolated conditions
- Limited extrapolation capabilities with non-physical models leading to limitation for real world predictions

Our solution

GT AutoLion
Lithium-ion Battery Simulation







Key to choose the best BMS and charging strategy:

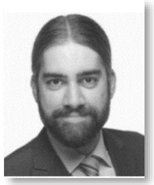
- Address the limitations of todays extrapolation on degradation
- Gain insights on the non-measurable quantities of vehicle operation
- Enable real-world fleet estimation
- Detect warranty issues and failures in cells

Enable a future multi-technique approach: Integrate fully predictive AutoLion battery models with AI data analytics & cloud monitoring

Presenter

Joshua Enriquez Geppert
Business Development at Gamma Technologies GmbH

Shreyas Lele
Application Engineer | Electric Systems at Gamma Technologies GmbH



Peter Stopp
EU Team Lead| Energy Conversion at Gamma Technologies GmbH

Michael Vallinder
Electric Powertrain Division | SCANIA

About Gamma Technologies, LLC

Gamma Technologies since 1994

Chicago Headquarters

Today

- **Industry's Tool of Choice for System Modeling**
- **High Productivity and Cost Advantage**
- Highly acclaimed Simulation Platform
- Over 800 Customer all around the World
- Over 1,000 Customers Success Stories available on our website

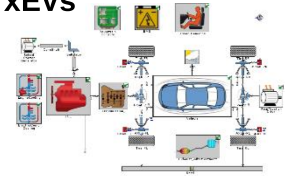
2021

GT-AutoLion Lithium-ion Battery Simulation

2018
Predictive Battery

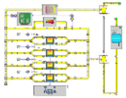
GT-SUITE

2002
Full Vehicle Platform
incl. **xEVs**



GT-POWER

1994
Predictive Engine

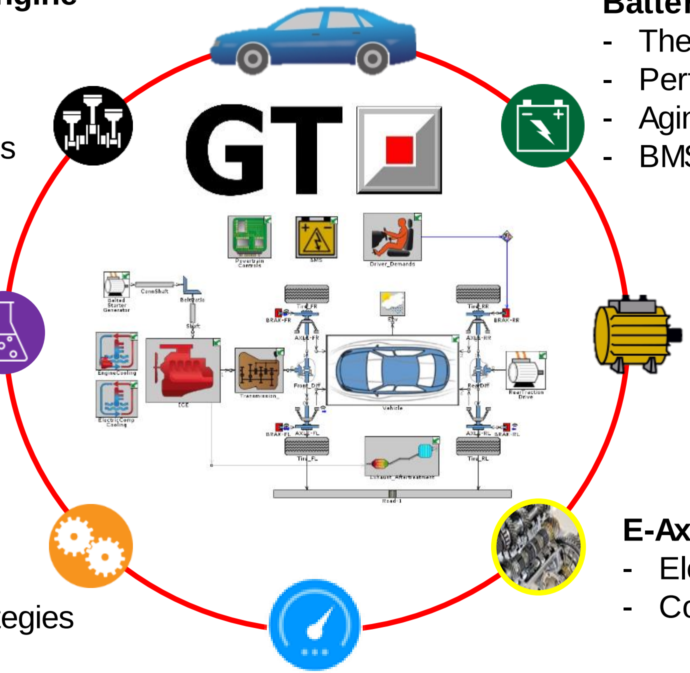


GT SUITE: Virtual Powertrain Components and Platform

Virtual Vehicle

Internal Combustion Engine
- Controls Optimization
- Design Variations
- Acoustics
- Engine Raw Emissions
- Cold Start Behavior

Battery
- Thermal Management
- Performance
- Aging and Degradation
- BMS



Aftertreatment
- Coating Materials
- Design Optimization
- Chemical Conversion
- Engine-Out Emissions

E-Motor
- Thermal Management
- Performance

Transmission
- Load Balancing
- Operating Strategies

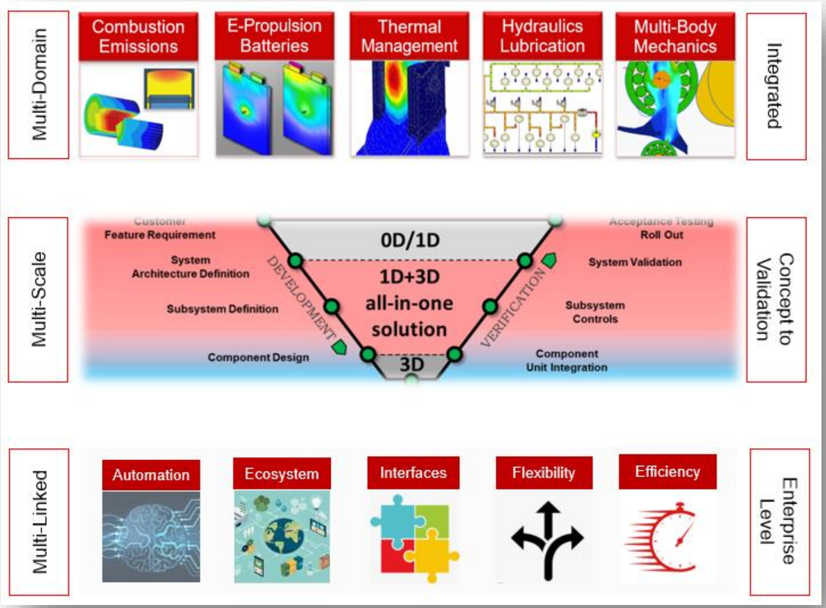
E-Axle
- Electrical and Mechanical Load Balancing
- Controls and Operating Strategies

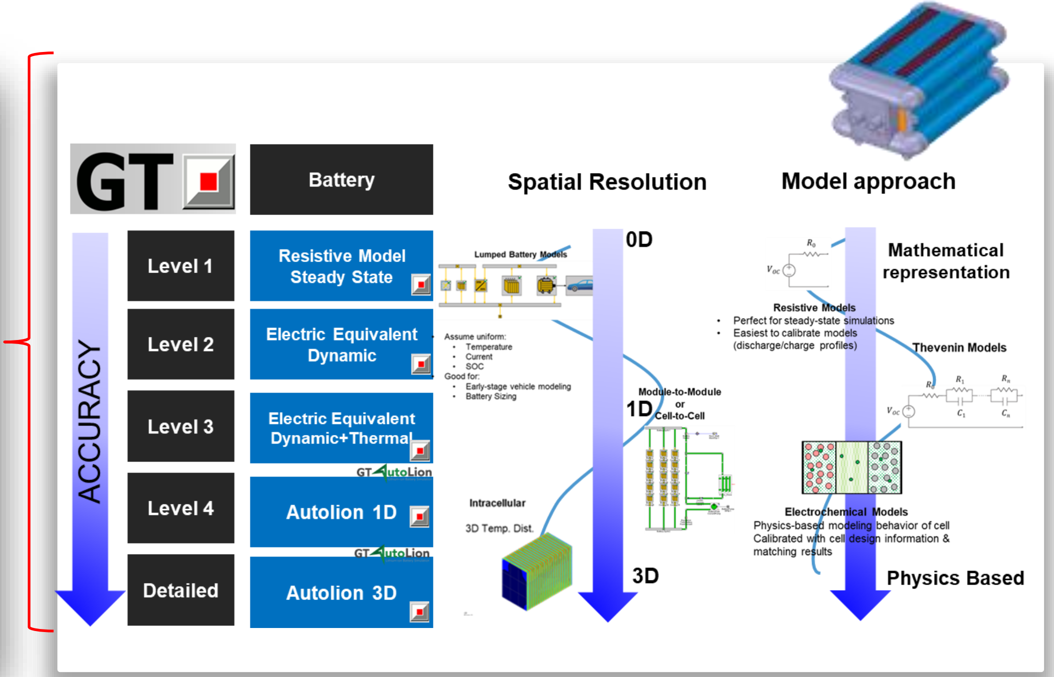
Evaluation in virtual Real Driving Cycle
- Fuel and Energy Consumption
- CO_2-Emissions and Pollutants
- Acoustics Legislation

Our Technology & Products

Enterprise-Level Platform with scalable architecture to meet current and emerging industry requirements

Battery modelling – at all fidelity level!





Unlock next generation of high-performance battery systems

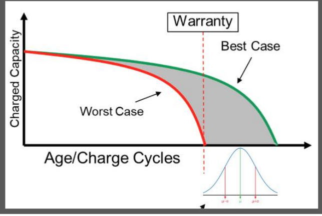
Electric Vehicle BMS: Establish a game-changing approach different from todays data driven single-technique

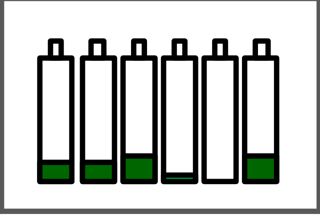
Common limitations today

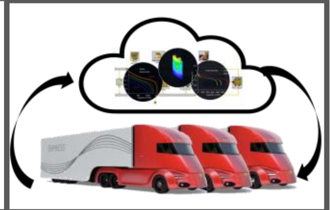
- The approach is heavily relying on data driven insights
- Large part of the system development is based on indications gained from cell tests and isolated conditions
- Limited extrapolation capabilities with non-physical models leading to limitation for real world predictions

Our solution

GT AutoLion
Lithium-ion Battery Simulation







Key to choose the best BMS and charging strategy:

- ➢ Address the limitations of todays extrapolation on degradation
- ➢ Gain insights on the non-measurable quantities of vehicle operation
- ➢ Enable real-world fleet estimation
- ➢ Detect warranty issues and failures in cells

Enable a future multi-technique approach: Integrate fully predictive AutoLion battery models with AI data analytics & cloud monitoring

Challenges: Fleet & Battery Lifetime prediction

Predict battery lifetime for vehicles according to their specific driving usage.

GT AutoLion
Lithium-ion Battery Simulation

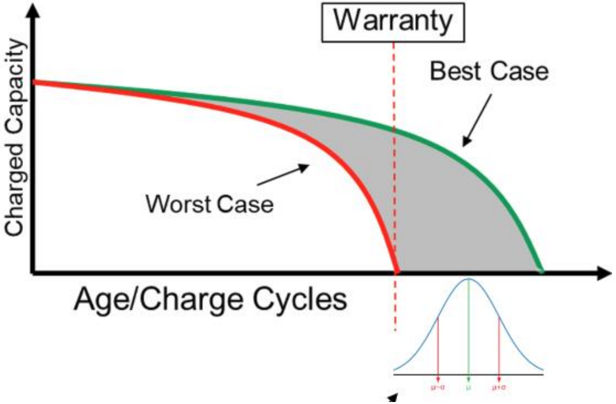
Digital Twin: PREDICTIVE AUTOLION MODEL

Vehicle in-use phase

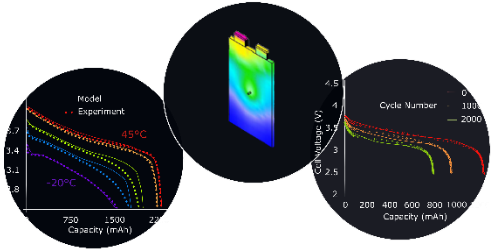
TESTING

Traditional models

Controls strategy? Range, performance, battery life-time, fleet aging



Limited cell & vehicle tests / isolated conditions / complex aging



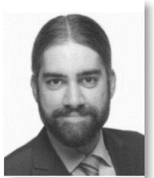
BMS

- Optimization of vehicle & battery operation strategy to maximize **electric range** and **lifetime**
- **Prediction of battery's end of life**
- Identify **damaging scenarios**
- Identification of routes that drive **aging**

Presenter

Joshua Enriquez Geppert
Business Development at Gamma Technologies GmbH

Shreyas Lele
Application Engineer | Electric Systems at Gamma Technologies GmbH



Peter Stopp
EU Team Lead| Energy Conversion at Gamma Technologies GmbH

Michael Vallinder
Electric Powertrain Division | SCANIA

Agenda

- Early-stage Battery Selection & Sizing Trade-off studies
- Identify aging effects under all operating conditions
- Push conflicting goals of the BMS to a secure limit and choose the best trade off
- Integrate predictive AutoLion battery models with AI

Early-stage Battery Selection & Sizing Trade-off studies

Early-stage Battery Selection & Sizing Trade-off studies

GT-AutoLion
Lithium-Ion Battery Simulation

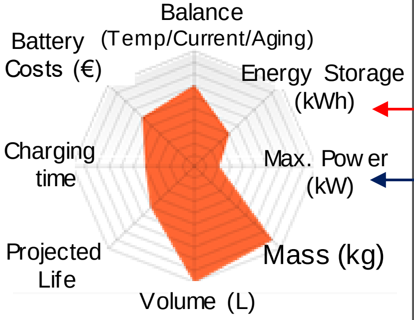
Virtually setup modular battery packs to study battery characterisics in the context of the vehicle requirments

Vehicle in-use phase

Various Topologies

Vehicle Topology	Battery Energy	Battery Power
HEV	1.5 kWh	40 kW
PHEV	12 kWh	60 kW
BEV	60 kWh	170 kW
FCEV	1.5 kWh	40 kW
MHEV	0.5 kWh	10 kW

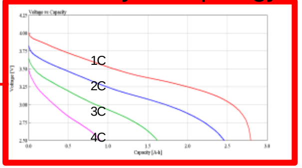
Select best matching Cell & Battery Pack for topology & requirements for fleet and markets



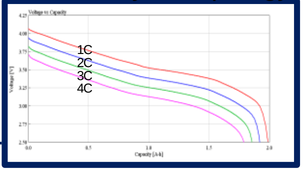
Translate requirements from topology to cell characteristics

DOE Setup

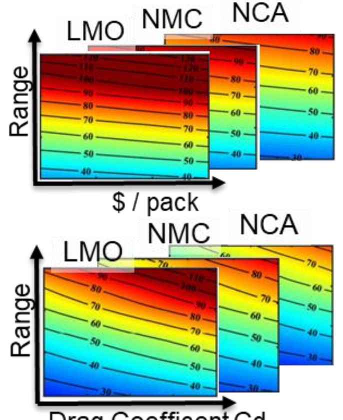
Best battery for topology A



Best battery for topology B

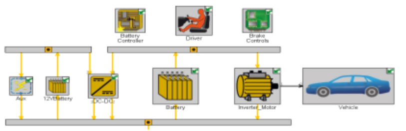


Design Optimizer



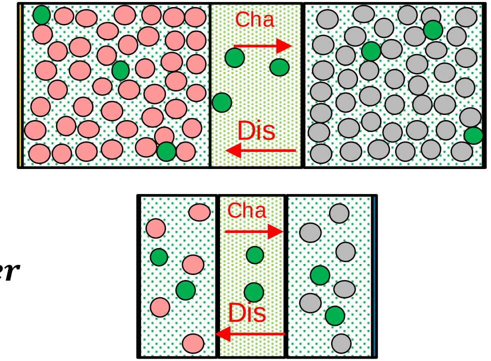
Carnegie Mellon University

Topologies



Early-stage Battery Selection & Sizing Trade-off studies

Cell designer



$Electrode\ thickness, loading$

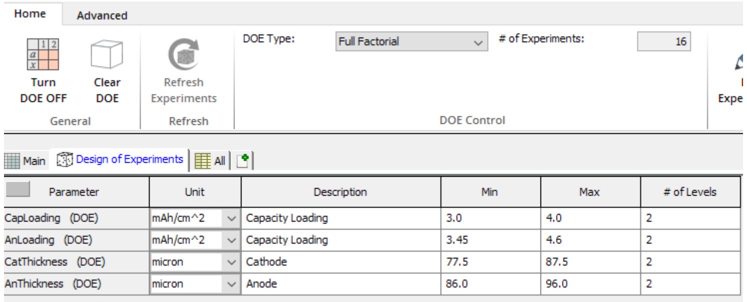
$Capacity_{cell}$
$Power_{cell}$
$Energy_{cell}$

GT AutoLion

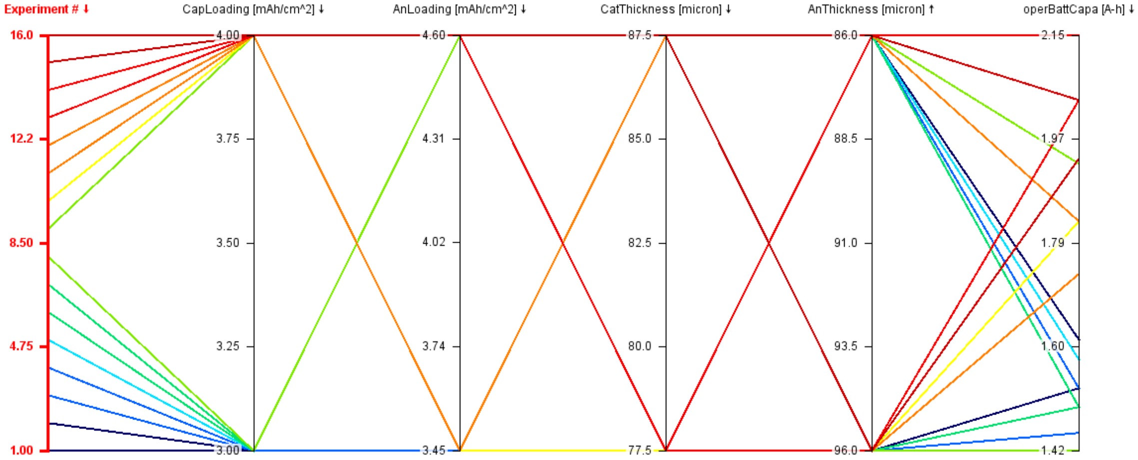
Full Cell Model

- Energy density
- Power density
- Operational capacity

Model DoE setup

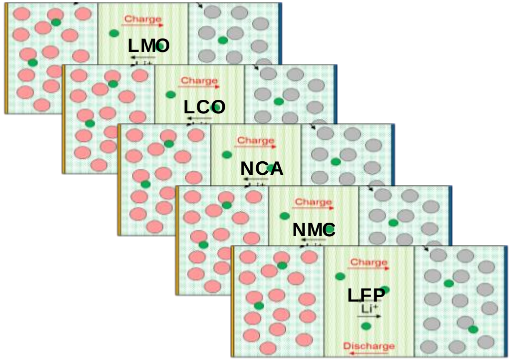


Parameter	Unit	Description	Min	Max	# of Levels
CapLoading (DOE)	mAh/cm^2	Capacity Loading	3.0	4.0	2
AnLoading (DOE)	mAh/cm^2	Capacity Loading	3.45	4.6	2
CatThickness (DOE)	micron	Cathode	77.5	87.5	2
AnThickness (DOE)	micron	Anode	86.0	96.0	2



Early-stage Battery Selection & Sizing Trade-off studies

Cell buyer



Battery library

$N_{Series}, N_{Parallel}$

$mass_{Batt}$

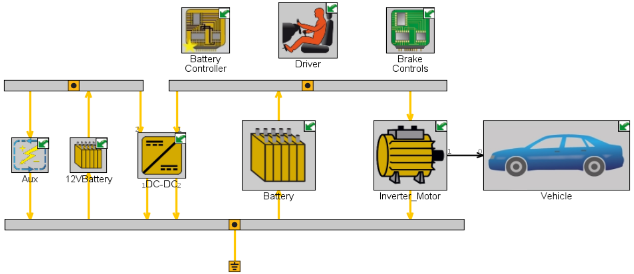
$Volume_{Batt}$

$Cost_{Batt}$

GT-AutoLion

Full System Model

- Range
- Performance
- Battery Lifetime
- Product Cost
- Operational Cost



Main | Model Setup | Cathode | Anode | Assembly

	Attribute	Unit	Object Value
	Cell Geometry		
	Cell Geometry		18650-Geometry
	Pack Model		
☑	Build Lumped Pack Model		
	Number of Series Cells		[Cells_Series]
	Number of Parallel Cells		[Cells_Parallel]
	Analysis Mode		
	Analysis Mode		Time Simulation
	Time Simulation		
	Load Type		Electrical Connections
	Initialization		
	Initial State of Charge	fraction	0.8
☐	Initialize as Aged Model		

Parameter	Unit	Description	Case 1	Case 2	Case 3
Case On/Off		Check Box to Turn Case On	☑	☑	☑
Case Label		Unique Text for Plot Legends	FTP75	WLTC	GT-RealDrive
TargetSpeed	km/h	Target Speed (i.e Drive Cycle)	FTP75_kph	WLTC_Class3	Großglockner
SimulationDuration	s	Maximum Simulation Duration (Time)	1874	1180	14400
FDR		Final Drive Ratio	7.05	7.05	7.05
InitialTemp	C	Initial Temperature	20	20	20
CellsInSeries		Number of Series Cells	100	100	100
CellsInParallel		Number of Parallel Cells	70	70	70

Agenda

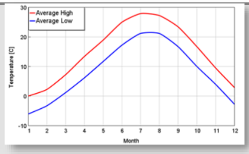
- Early-stage Battery Selection & Sizing Trade-off studies
- Identify aging effects under all operating conditions
- Push conflicting goals of the BMS to a secure limit and choose the best trade off
- Integrate predictive AutoLion battery models with AI

Identify aging effects under all operating conditions

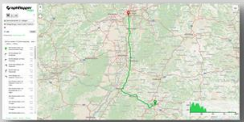
Perform accelerated aging and identify effects under all operating conditions

GT-AutoLion
Lithium-ion Battery Simulation

Vehicle in-use phase



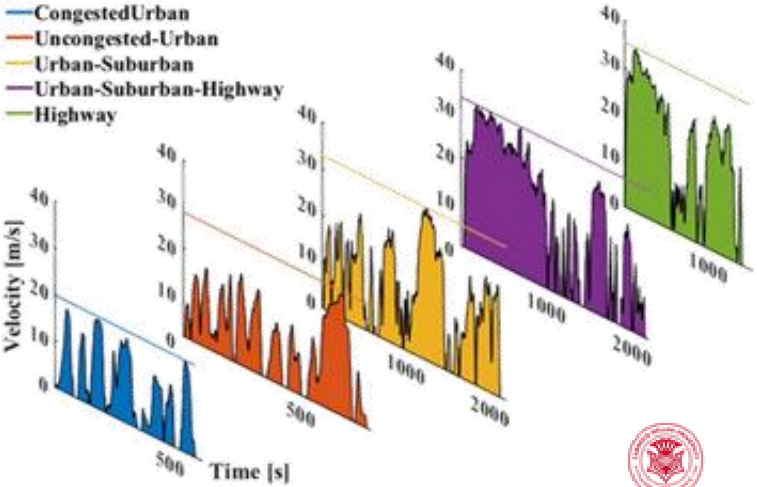
Weather Patterns

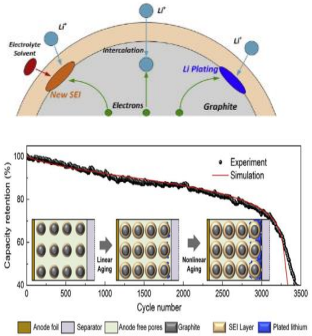


Commuting Behavior

Charging Patterns

Study impact of driving routes & weather on **end of life and optimize control strategy**





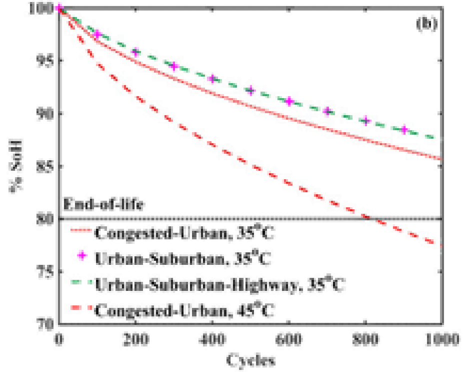
SEI Layer Growth

Internal resistance growth

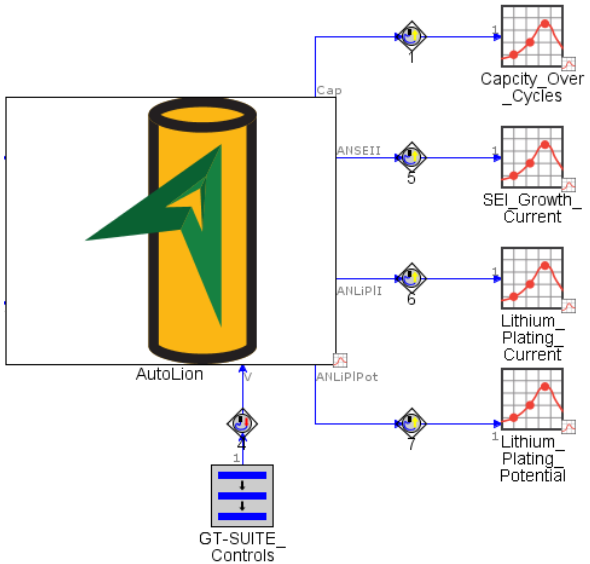
Li-plating

Lithium loss

End of Life



Flexibility in simulating Real World Aging



- GT-SUITE Control library
- GT-RealDrive
- Co-simulation
  - MATLAB/Simulink
  - Python

- Imposes load on the Battery Pack depending on:
  - Time and date, Temperature
  - Charging patterns

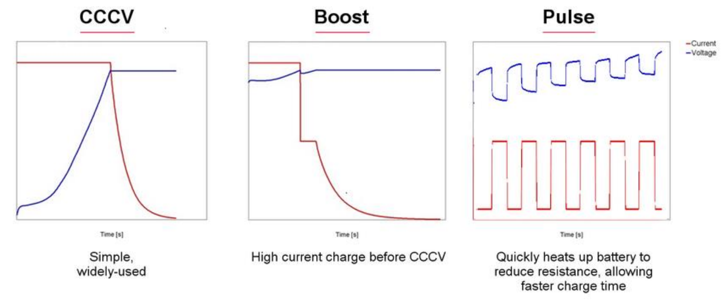
Normal Week

Day	Start	Description
Sun		Rest
Mon-Fri	06:30	Drive to work
		Rest
	17:00	Drive home
		Rest
Sat	11:00	Errands
		Rest

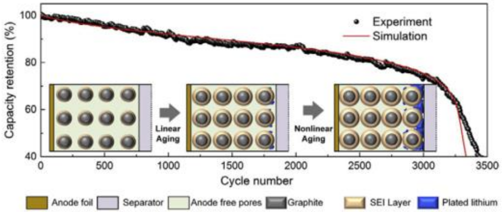
Vacation Week

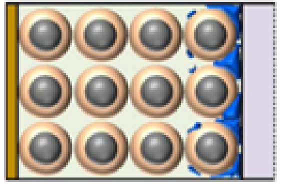
Day	Start	Description
Sun	11:00	Drive to Destination
		Rest
Mon-Fri		Rest
Sat	11:00	Drive home
		Rest

(simulated every 13th week)



Identify aging effects under all operating conditions





Battery Aging

Capacity loss

Power loss

SEI layer growth

Lithium plating

Active material isolation

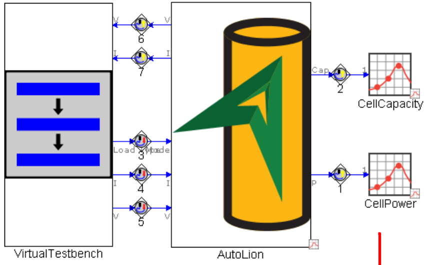
High temperature discharge

Low temperature charge

Over charge and Over discharge

High depth of discharge

Storage SoC



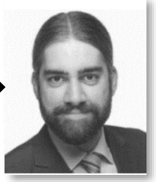
Presenter

Joshua Enriquez Geppert

Business Development at Gamma Technologies GmbH

Shreyas Lele

Application Engineer | Electric Systems at Gamma Technologies GmbH



Peter Stopp

EU Team Lead| Energy Conversion at Gamma Technologies GmbH

Michael Vallinder

Electric Powertrain Division | SCANIA

Agenda

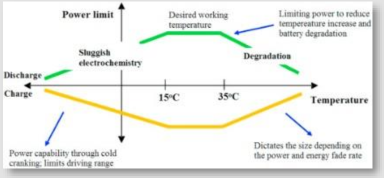
- Early-stage Battery Selection & Sizing Trade-off studies
- Identify aging effects under all operating conditions
- Push conflicting goals of the BMS to a secure limit and choose the best trade off
- Integrate predictive AutoLion battery models with cloud monitoring

Push conflicting goals of the BMS to a secure limit and choose the best trade off

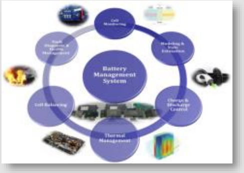
Push conflicting goals of the BMS to a secure limit and choose the best trade off.

Vehicle in-use phase

Drive Cells in comfort zone



Smart Battery Management System



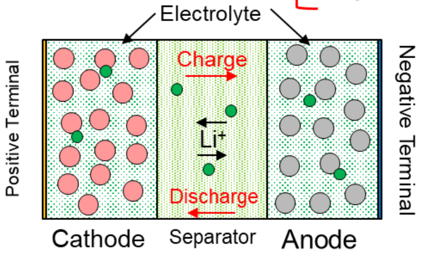
Smart Vehicle Energy Management

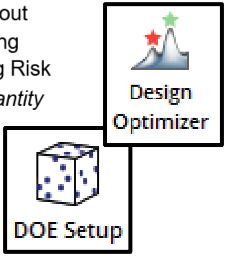
AutoLion **physical models** give insights to the **non measuarable quantities** which are essential to gain full control **over complex trade offs for fleet and life time**.

Current →
Initial Temp →
Initial SOC →

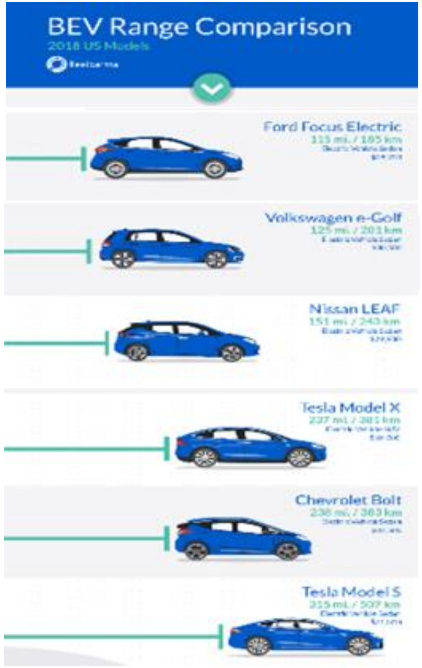
→

- Battery Temperature
- Terminal Voltage
- Capacity Fade
- SOH, SOC out
- Cell Swelling
- Lithium Plating Risk
- *Any other quantity*

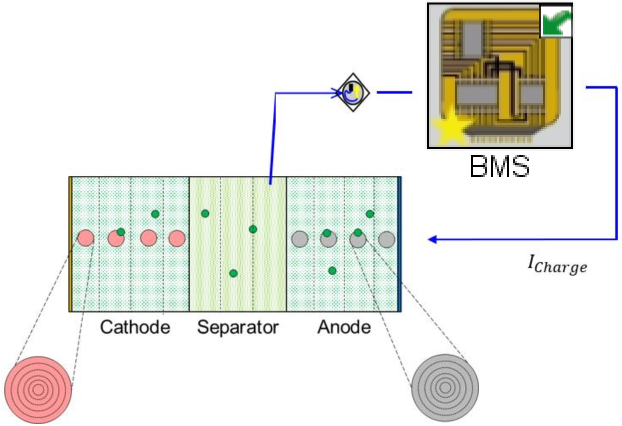




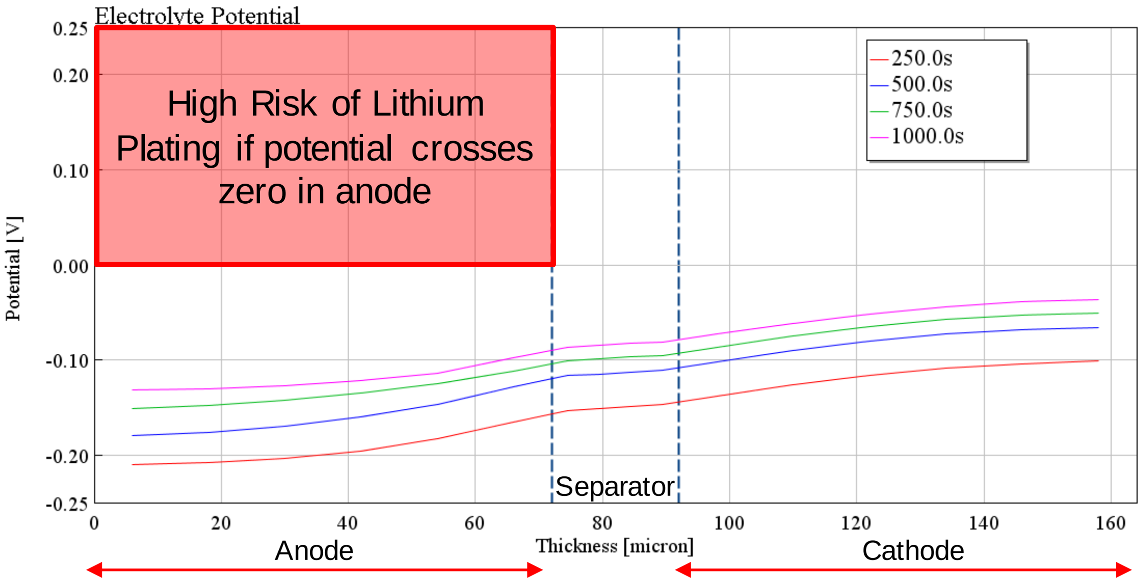
Trade off for Optimal Range



Push conflicting goals of the BMS to a secure limit and choose the best trade off

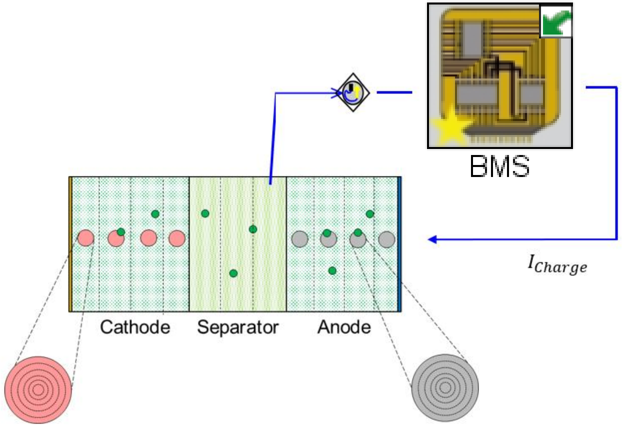


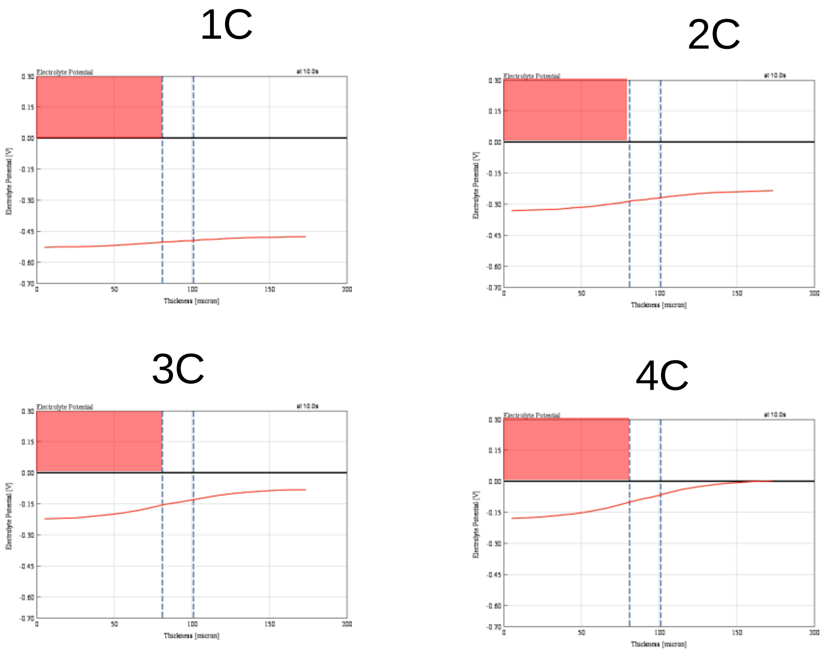
Electrolyte Potential plots at 1C at various time stamps:



$$\boldsymbol{Lithium\ Plating\ Potential} = \varphi_{Electrolyte} - \varphi_{Solid}$$ (at Anode-Separator Interface)

Push conflicting goals of the BMS to a secure limit and choose the best trade off



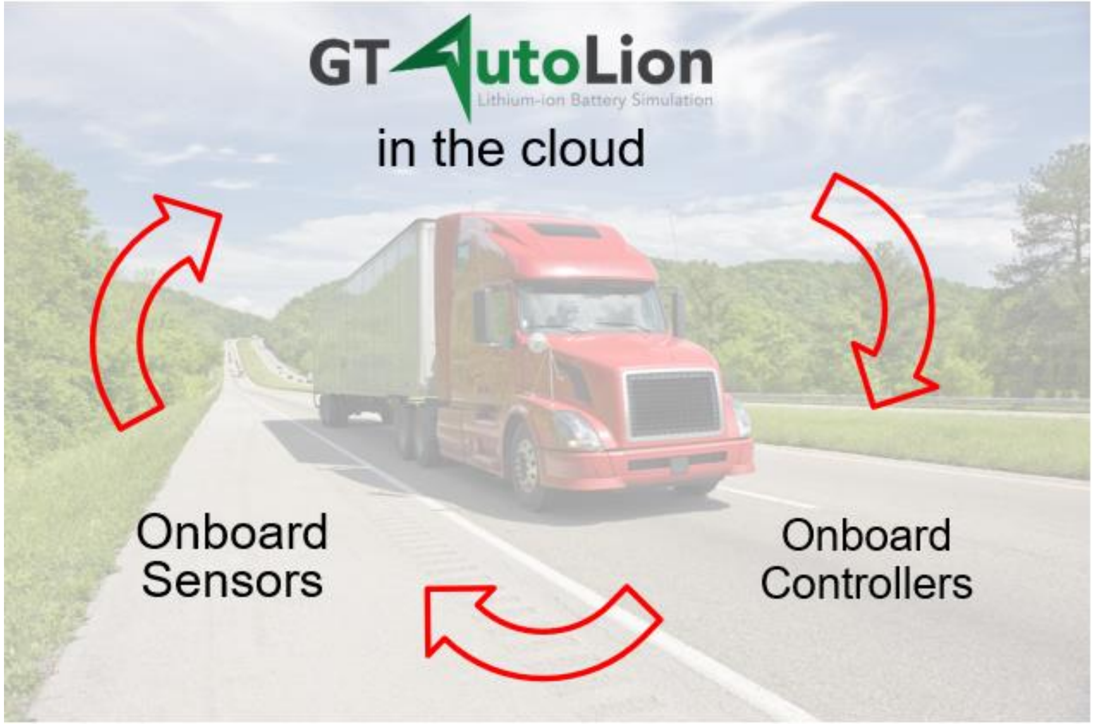


$$\boldsymbol{Lithium\ Plating\ Potential} = \varphi_{Electrolyte} - \varphi_{Solid}$$ (at Anode-Separator Interface)

Agenda

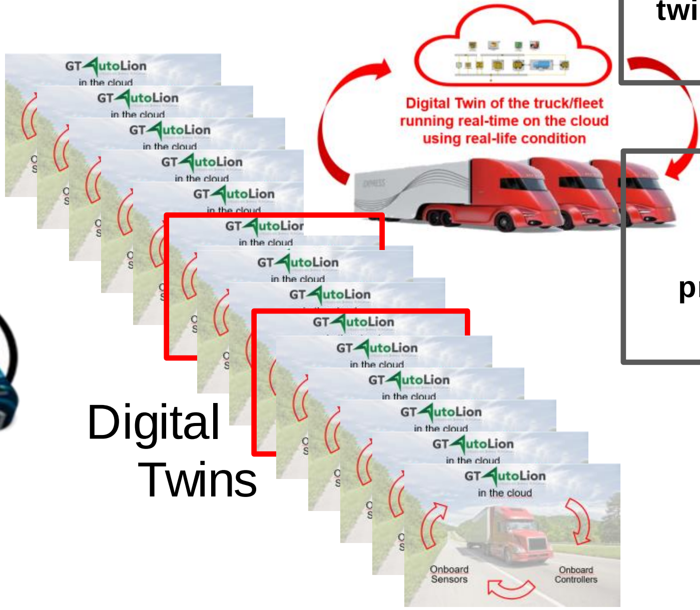
- Early-stage Battery Selection & Sizing Trade-off studies
- Identify aging effects under all operating conditions
- Push conflicting goals of the BMS to a secure limit and choose the best trade off
- Integrate predictive AutoLion battery models with cloud monitoring

Integrate predictive GT-AutoLion battery models with cloud monitoring



Integrate predictive GT-AutoLion battery models with cloud monitoring

- Enable a future multi-technique approach
- Integrate predictive AutoLion battery models with AI data analytics & cloud monitoring



Digital Twins

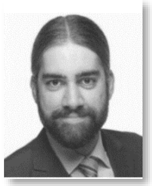
Warranty
Avoid expensive malfunction with digital twin that captures life degradation

Warranty
Avoid warranty problems by smart communication

Presenter

Joshua Enriquez Geppert
Business Development at Gamma Technologies GmbH

Shreyas Lele
Application Engineer | Electric Systems at Gamma Technologies GmbH



Peter Stopp
EU Team Lead | Energy Conversion at Gamma Technologies GmbH

Michael Vallinder
Electric Powertrain Division | SCANIA

Michael Vallinder

Autolion usage at scania

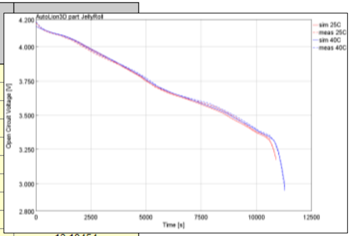
Content

- How AutoLion is used throughout the development process
- Explain how we use it our contact with suppliers
- Use the model as a ”virtual sensor” to aid and expand testing
- Example of aging simulations to predict and expand aging tests
- Show the software-in-the-loop integration

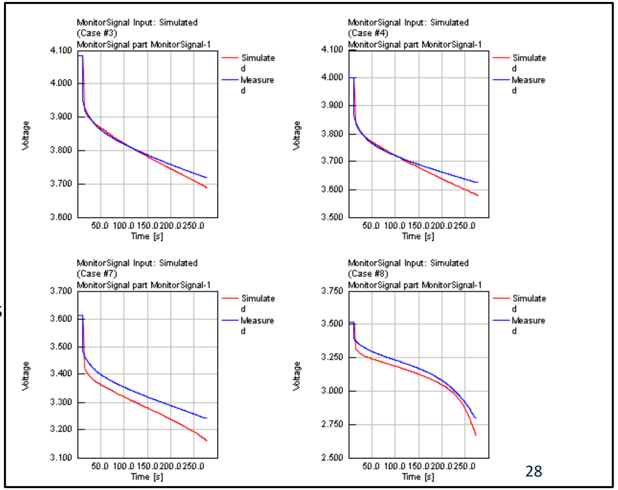
Performance simulations – AutoLion1D

- **Iterate predictive model**
  - Design the cell based on previous knowledge, literature or dialog with supplier
  - Study results from design report, OCV, capacity
  - Run simulations to figure out DC-IR characteristics
  - Find the ”big” parameters such as electrode thicknesses, particle size and Li+ loading to match requirements and cost

	Cathode: NCM 811+NCM 811	
Porosity	0.184	
Capacity Loading (mAh/cm^2)	3.679	
N/P Ratio		
Mass Loading (mg/cm^2)	18.2469	
Dry Electrode Density (g/cm^3)	3.65	
Active Material Used (g)	896.9946	
First Charge Capacity (Total) (Ah)	188.36887	
Irreversible Capacity (Total) (Ah)	5.88482	
First Charge Capacity (Participating) (Ah)	188.36887	
Irreversible Capacity (Participating) (Ah)	5.88482	13.19454
Reversible Capacity (Ah)		



- **Calibrate virtual twin**
  - Perform calibration of the model to available test data
  - With skilled initial guesses not much calibration is needed
  - Information is key, with more test data and design information from supplier or tear-down the better
  - After successful calibration one can implicitly trust the model to accurately predict exchange currents and similar parameters that are necessary for the aging simulations



- **Testing**
  - Perform test plan virtually with AutoLion to identify gaps or redundancies in the test plan
  - Perform cell testing

- **Requirements specification**
  - Try to buy the proposed cell

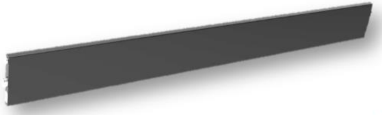
AutoLion1D in dialogue with suppliers

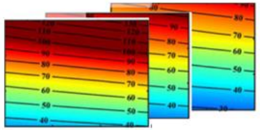
- **Requirements specification rev1**
  - Suggestions from suppliers

Supplier A cell 1

Supplier B cell 1

Supplier B cell 2



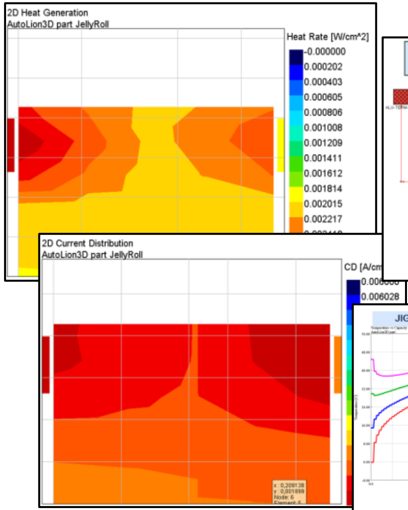


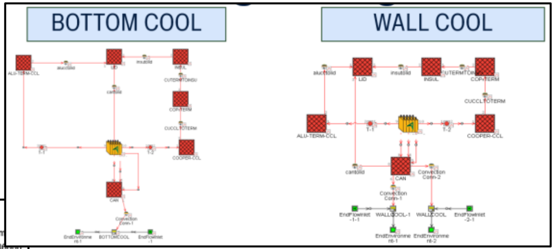
GT-AutoLion
Lithium-ion Battery Simulation

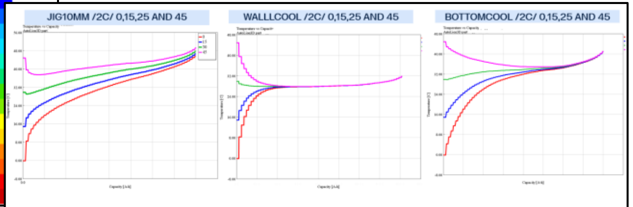
- **Initial assessment**
  - Create models for interesting cells
  - Correct accuracy, quick-and-dirty just to understand the different suggestions
  - Heat rejection problems, fundamental DC-IR differences
  - Jelly Roll temperature and performance uniformity
  - Already here we start to follow the product from idea to first prototype to verified production cell with our virtual twin in GT-AutoLion
- **Understand the product**
  - To have a good relation with the supplier we need to ask the correct questions and state clear demands
  - GT-AutoLion is a great tool for understanding our own demands and also understand the limitations from the supplier
  - Use these models to understand what happens to the requirements if we settle for 1C charging instead of 5C as an example
  - Understand the pricing, try to figure out what goes into a certain cell to understand why one supplier is cheaper but worse or better but costly (typically design of electrode layers)
- **Requirements specification rev2**
  - Essentially the purchasing process is front loaded with better and more informed requirements

Expand on the details with AutoLion 3D

- ## AutoLion 3D model
  - With the electrochemical properties calibrated in the virtual twin additional details are added with AutoLion3D
  - By modelling the thermal aspects in detail the virtual twin can answer interesting engineering questions
  - The first task could be to understand the test setup and rig construction to know what is actually being tested/measured

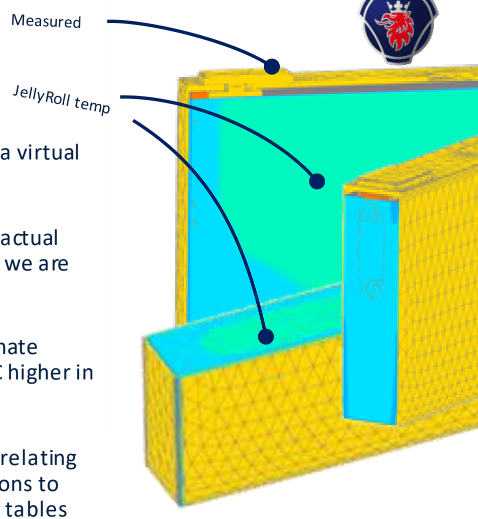


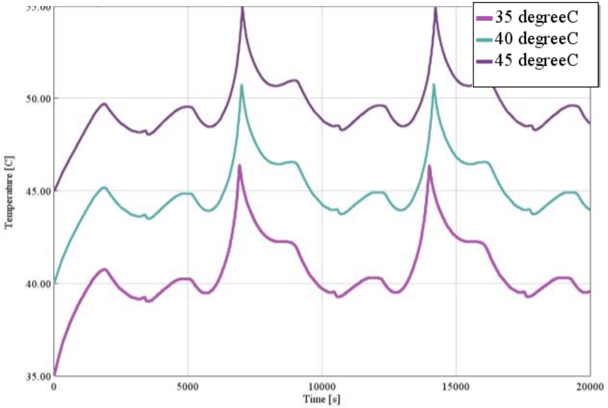




Heat transfer is maximum through the walls and convective cooling the walls helps to bring the temperature of jelly roll down really fast.

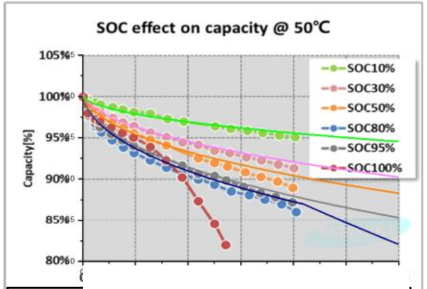
- ## Virtual sensor
  - The detailed model can be used as a virtual sensor to complement test data
  - Measured temp is not the same as actual temp in the jelly roll, which is what we are interested in
  - It showed that a 35,40,45 degC climate chamber tests were actually 5 degC higher in the Jelly Roll respectively
  - This is important to know when correlating data, requirements and BMS functions to measured temperatures or look-up tables

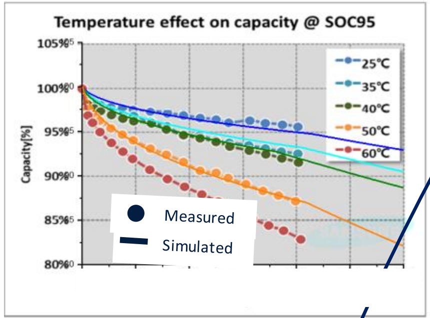


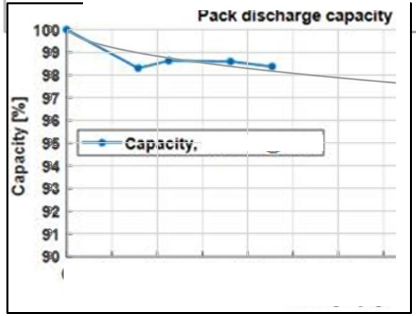


Aging Simulations – AutoLion1D

- **Calibrate virtual twin to test data**
  - Same as performance calibration just that the focus now is on aging mechanics
  - Calendar, cyclic and drive cycle data is used to calibrate the aging parameters

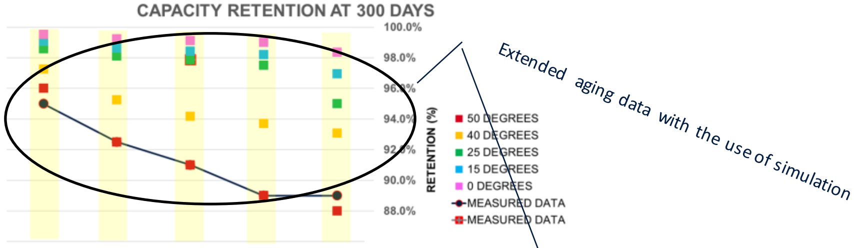


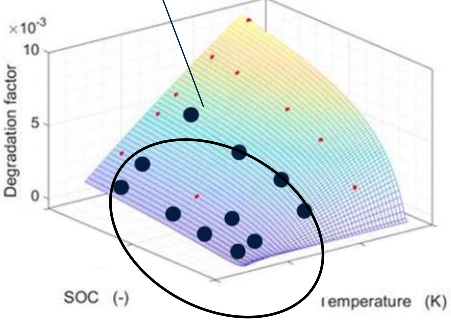




- **Make predictive model**
  - Use all available test data and construct a model capable of predicting the data it is calibrated to
  - Use this model to simulate aging behaviour ahead in time or for different use cases that aren't in the planned testing

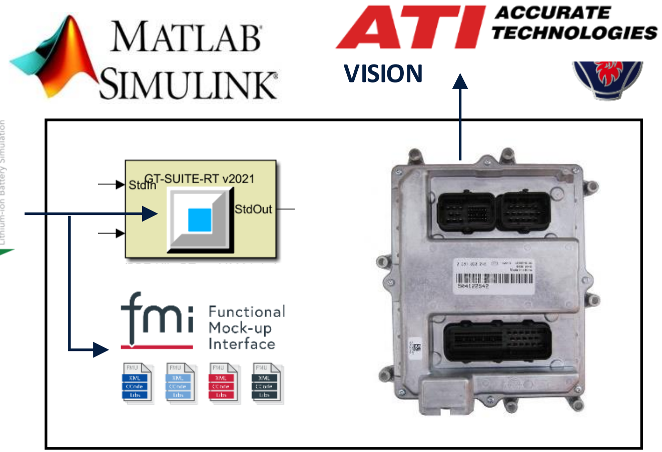
- **Simulate aging**
  - Expand on the test matrix with additional simulated aging tests
  - 'See into the future' and revise test matrix
  - Perform additional aging simulations for problems that were not thought of





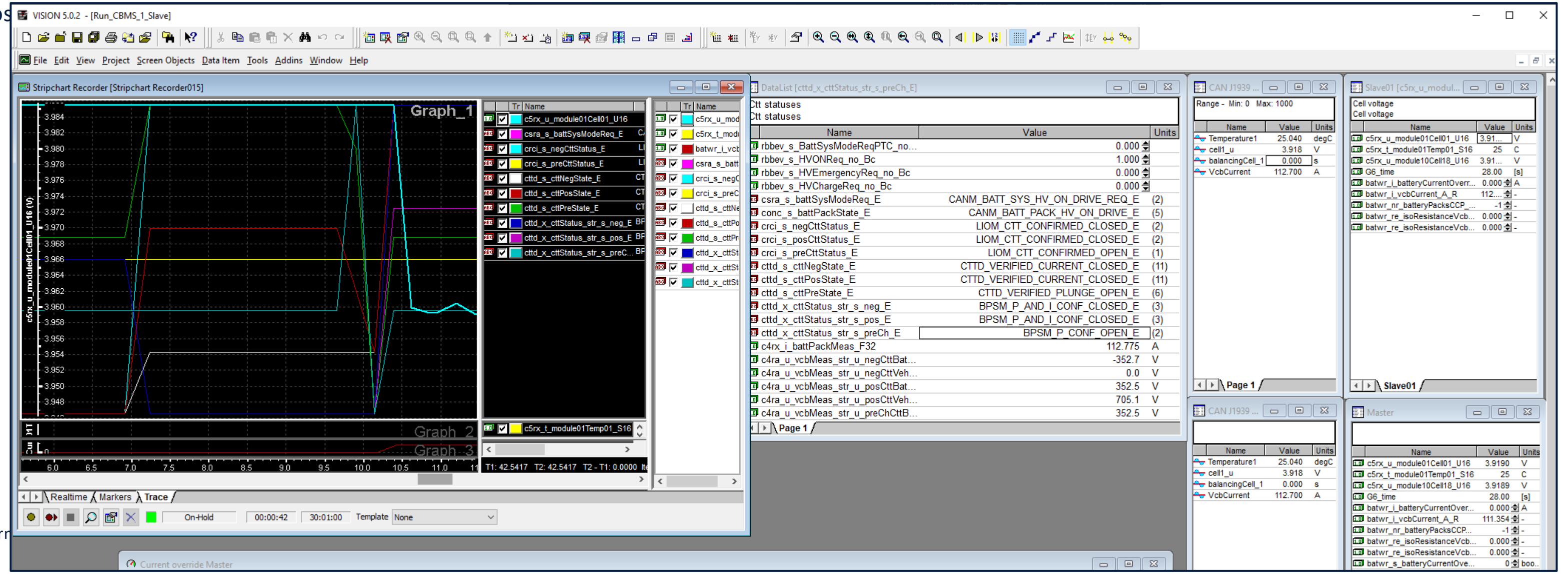
Software in the Loop – AutoLion1D

- **GT-AutoLion model for SiL**
  - GT-AutoLion provides insight into immeasurable variables which is powerful in software development
  - E.g. How know SOC without a SOC model, how to make a model when SOC is not known ? (difficult to measure online)
  - The GT-AutoLion provides the "truth", Li+ stoichiometry, and can therefore be used to design the initial SOC model before any test data is available
  - This of course applies to aging as well, with AutoLion the aging is resolved in time and therefore it's pos



GT-AutoLion Lithium-ion Battery Simulation

Battery Temperature
Terminal Voltage
Capacity Fade
SOH, SOC out
Cell Swelling
Lithium Plating Risk
Any other quantity



Info class Extern