e.GO – agile simulation to verify vehicle concepts in early development stages

March 2018

e.GO

e.GO

das Stadtauto

✓ **Fun** ✓ **Practical** ✓ **Affordable**

e.GO will boost e-mobility, exciting customers with cars that are fun, practical and affordable.

e.GO has clearly positioned itself since the company's foundation and is shaping a new form of electromobility

Fun

- Acceleration 0 - 50 km/h: 3,2 sec
- Agile & maneuverable
- Inspiring design
- Safety first

Practical

- Made for most daily needs and ranges
- Compact exterior and interior
- First choice for second car

Affordable

- Price from 15.900 €; before subsidies
- Total Cost of Ownership (TCO) 40% lower than conventional cars
- Worthwhile without subsidies

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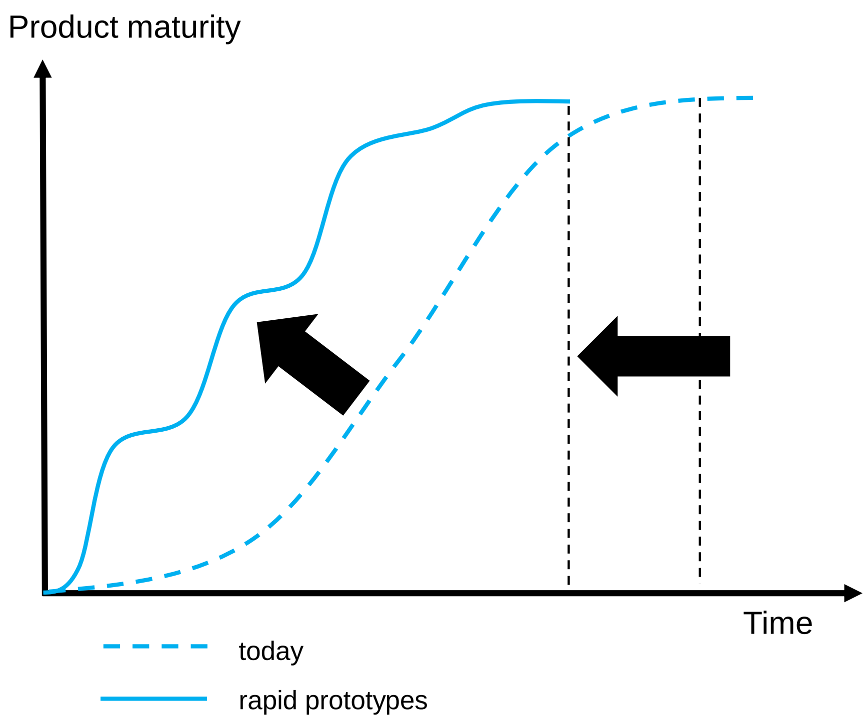
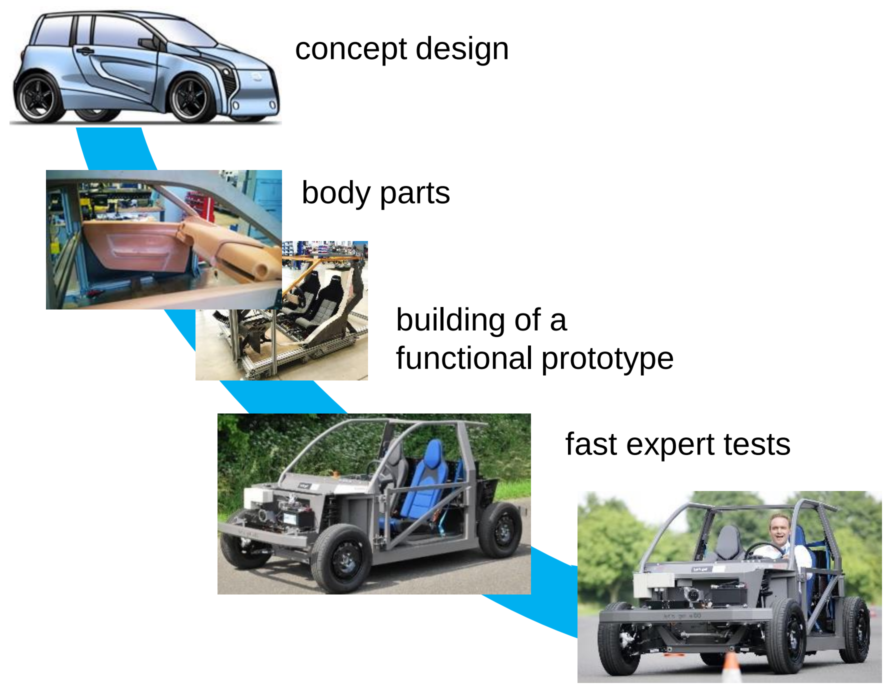
Highly iterative development is supported by the rapid implementation and testing of prototypes

Rapid implementation of prototypes ...



... the example of e.GO Life



The rapid market expedition with functional prototypes is a success factor in the development of radical innovations in the e-mobility market.

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e.GO enables the production of affordable vehicles with the latest technologies

How to develop a highly iterative Prototype?

Technology

1

E-Mobility

Introducing cleaner air and higher living standards

Digital Prototype

- *CAx – Design: DMU (Full-Vehicle Package)*
- *Digital Twin*
- *Simulation of Mechanical Strength (FEA)*
- *Full Vehicle Simulation – Ensuring Requirement Fit*

Physical Prototype

- *Process Validation*
- *Empowerment of Prototyping and Production Team*
- *Fast validation of Technical Concepts*
- *Durability Tests in early stages*

High Level Requirements

Concept`s abletility to fullfill the requirements

	e.GO Life 20	e.GO Life 40	e.GO Life 60
ENGINE POWER	20 kW	40 kW	60 kW
TOP SPEED	116 km/h	150 km/h	160 km/h
ACCELERATION 0-50 km/h	6.6 sec.	4.1 sec.	3.2 sec.
ACCELERATION 0-100 km/h	35.0 sec.	12.0 sec.	8.6 sec.
ELECTRIC RANGE NEDC	136 km	146 km	194 km
ELECTRIC RANGE Actual City Traffic	104 km	114 km	154 km
BATTERY CAPACITY	14.9 kWh	17.9 kWh	23.9 kWh
CONSUMPTION 100 km (NEDC)	9.9 kWh	10.9 kWh	11.1 kWh
CHARGING TIME Schuko Plug; 230 V	6.0 hrs	7.5 hrs	9.8 hrs
CHARGING TIME IEC Type 2 Connector; Single Phase	3.1 hrs	3.6 hrs	4.6 hrs
DIMENSIONS	3348 x 1700 x 1567 mm (L/B/H)		

Does the vehicle concept fulfill the requirements set by the product management?
→ To answer this question in an early development stage, e.GO used Matlab / Simulink to simulate the vehicle quite without a physical prototype.

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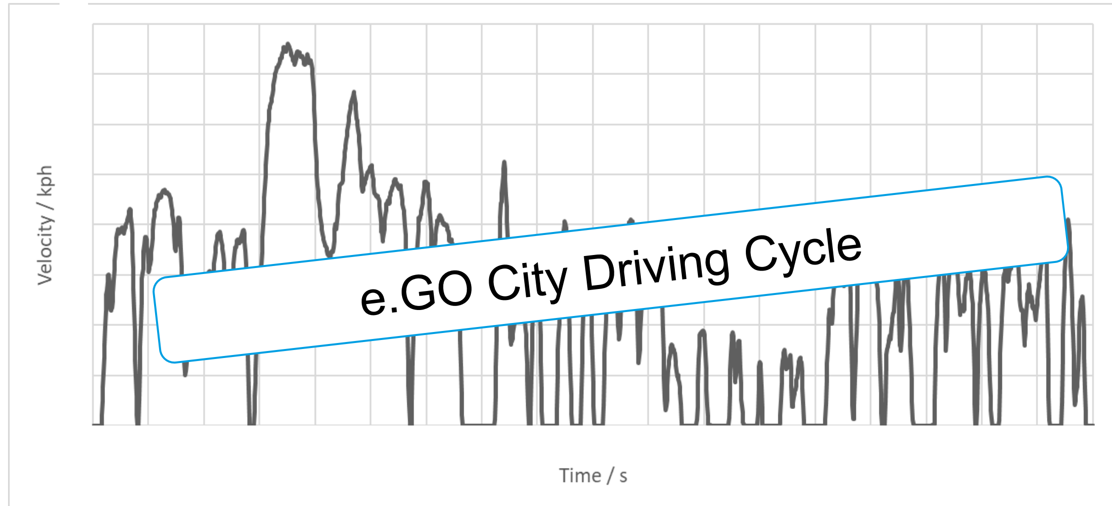
Driving Cycle / Testing

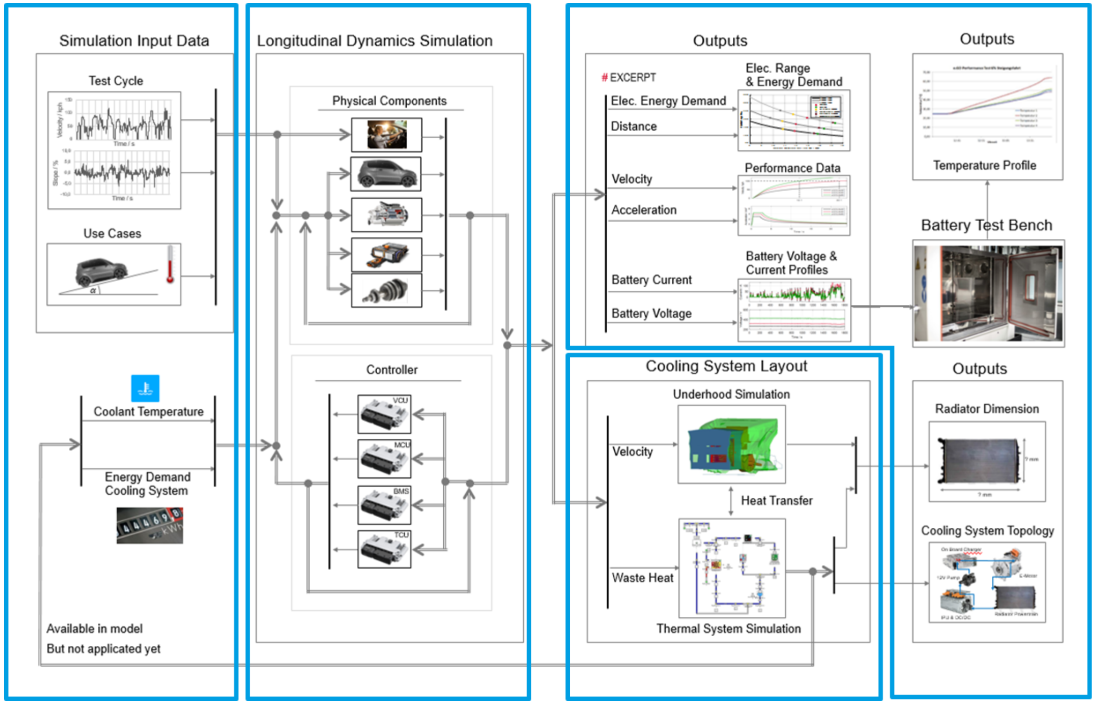
Developing a city cycle to fullfill customer requirements



- *a new car concept needs a new Driving cycle!*
- *Tracking of an inner-city driving cycle (s ~ 19 km, t ~ 45 min, $v_{(average)}$ = 25 km/h)*
- *also using standardcycles to ensure comparability to other vehicle concepts*

Simulation of an electric vehicle

Elements of the Simulation Model



Input Data

Physical Components

- ***Battery***
- ***Motor & Inverter***
- ***Gearbox***
- ***Cooling System***
- ***Vehicle***

Driver Model

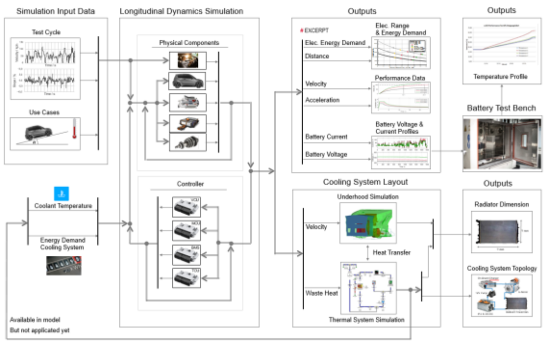
Controller Models

Output Data

- ***The complex interaction of components is simulated in the Simulink model***
- ***Validation of the model with rapid prototypes***

Validation

Elements of the Validation Process



Simulink Model

- -inclusion of all components
- Defining Environmental Inputs
- Defining Input & Output-Parameter

Funktional Prototype

- Testing of selective functions
- Improving the simulation model
- Increasing the prototype maturity

Final vehicle

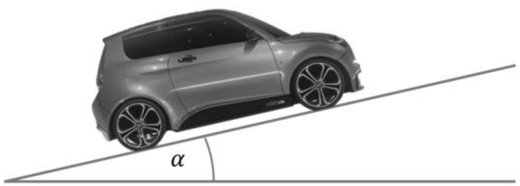
- Validation of the final system design
- Matching oh the physical vehicle and the simulation model

- ***Several Model-elements***
- ***Validation of model with rapid prototypes***
- ***Finalization of e.GO Life Vehicle Concept***

Vehicel Model

Longitutinal Dynamics Simulation

FAHRZEUG MODELL / FAHRZEUGWIEDERSTAND



$$P_{Req} = (F_{Air}+F_{Roll}+F_{\alpha}+F_{Accel})\cdot v$$

$$F_{Air} = \frac{1}{2}\cdot \rho_{Air}\cdot c_W \cdot A_{Veh}\cdot v^2$$

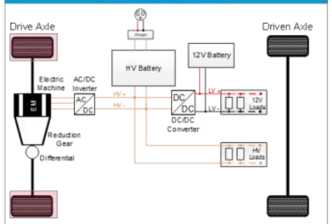
$$F_{Roll} = (m_{Veh}+m_{Add})\cdot g\cdot f_{Roll}\cdot \cos(\alpha)$$

$$F_{\alpha} = f_{Roll}\cdot (m_{Veh}+m_{Add})\cdot g$$

$$F_{Accel} = (m_{Veh}\cdot e + m_{Add})\cdot a$$

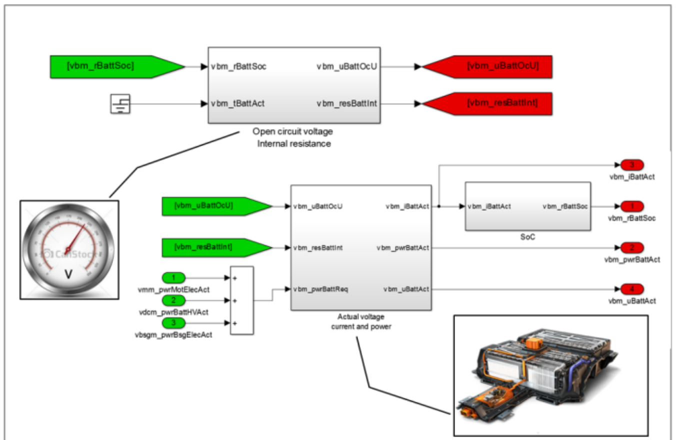
ρ_{Air} = Air density / (kg/m³)
c_W = Drag coefficient / -
A_{Veh} = Vehicle frontal area / m²
m_{Veh} = Vehicle mass / kg
m_{Add} = Additional mass / kg
g = Gravitational constant / (m/s²)
α = Inclination angle / rad
a = Acceleration / (m/s²)
v = Velocitiy / (m/s)
f_{Roll} = Rolling friction coefficient / -
e = Factor for rotational inertia / -

Beschreibung



- Basierend auf Fahrwiderstandsgleichungen für
  - Luftwiderstand
  - Rollwiderstand
  - Steigungswiderstand
  - Beschleunigungswiderstand

BATTERIEMODELL/ ÜBERBLICK



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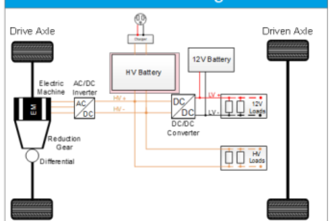

- Modell mit äquivalenter elektrischer Schaltung
- Energieverlust von Komponenten basiert auf dem Innenwiderstand

Vehicel Models – Driving resistance

- *Drag (Air resistance)*
- *Rolling resistance*
- *Acceleration resistance*
- *Slope resistance*

Battery Simulation

- *Internal resistance*
- *Thermal behavior*
- *SoC, DoD, SoH*
- *Current*
- *Voltage*

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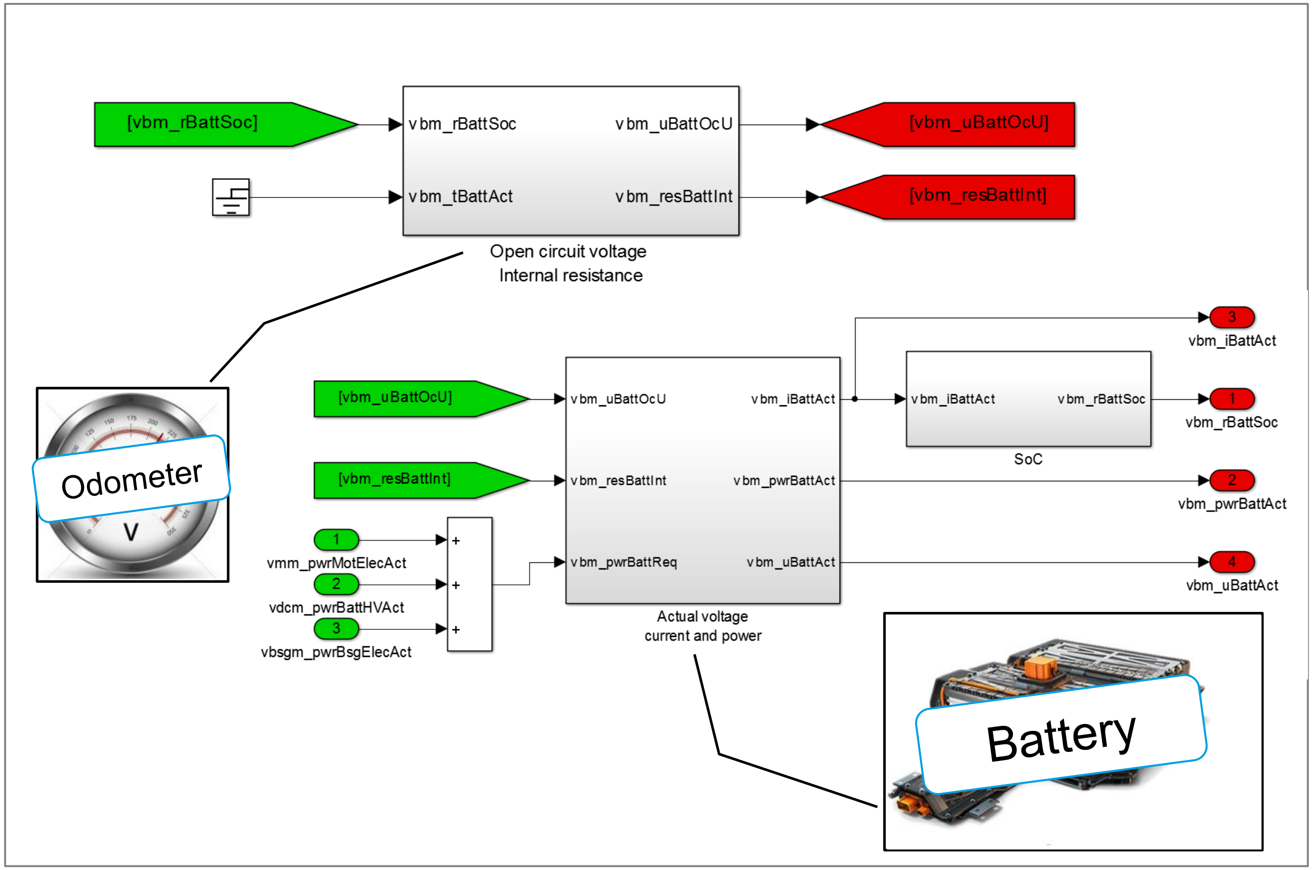
Modellbeschreibung und Simulationsmethodik

BATTERIEMODELL/ ÜBERBLICK



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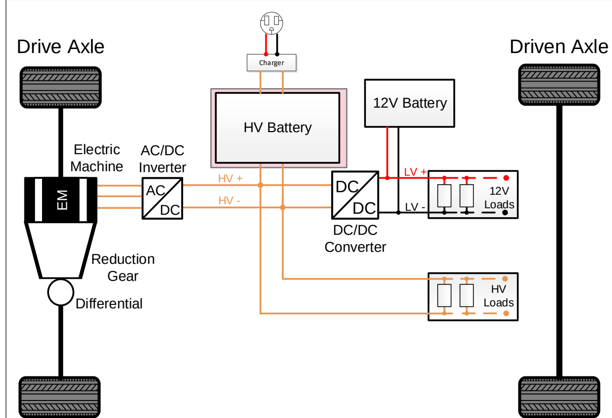

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Modellbeschreibung und Simulationsmethodik

BATTERIEMODELL / DETAIL

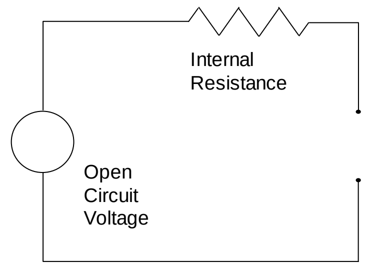
Physisches Modell

- Battery current is given by:

$$I_{Batt} = \frac{\left(V_{OC} - (V_{OC}^2 - 4P_{Batt,Req} \cdot R_{int})^{\frac{1}{2}}\right)}{2R_{int}}$$

- Battery voltage is calculated:

$$V_{Batt} = V_{OC} - R_{int} \cdot I_{Batt}$$



I_{Batt}	=	*Battery current / A*
V_{OC}	=	*Battery open circuit voltage / V*
V_{Batt}	=	*Battery voltage / V*
$P_{Batt,Req}$	=	*Power requested from battery / W*
R_{int}	=	Battery internal resistance / Ω

Eingang

- Eingangsgröße:
  - Leistung der EM
  - Leistung der Hochspannungsbatterie

Ausgang

- Ausgangsgröße:
  - Batterie SoC
  - Batteriestrom
  - Batteriespannung

Beschreibung

I_{Batt}:	Batteriestrom/ A
V_{OC}:	Batterie Leerlaufspannung / V
V_{Batt}:	Batteriespannung/ V
$P_{Batt,Req}$:	Leistungsanforderung von der Batterie / V
R_{int}:	Batterie Innenwiderstand / Ω

- Modell mit äquivalenter elektrischer Schaltung
- Energieverlust von Komponenten basierend auf dem Innenwiderstand

e.GO Mobile AG

Alexander Weis
Expert Powertrain & Battery Systems

Campus-Boulevard 30
52074 Aachen, Germany

Phone +49 241 47574 0
Mobile +49 151 2885 9985
E-Mail alexander.weis@e-go-mobile.com
Internet www.e-go-mobile.com