

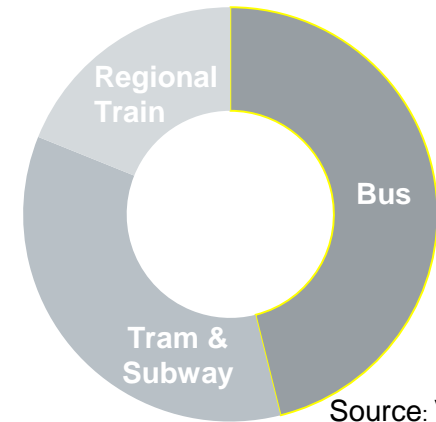


Electrical City Bus: Functional Safety through Driving Tests and Simulations

SAE 2017 Hybrid and Electric Vehicle Technologies Symposium
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Situation

- Currently bus fleets consist almost exclusively of vehicles with combustion engines
- City busses hold up to 46 % of urban public transportation in Germany
- City busses are an ideal supplement to other modes of transport due to their flexibility



Source: VDV

Advantages of City Bus Electrification

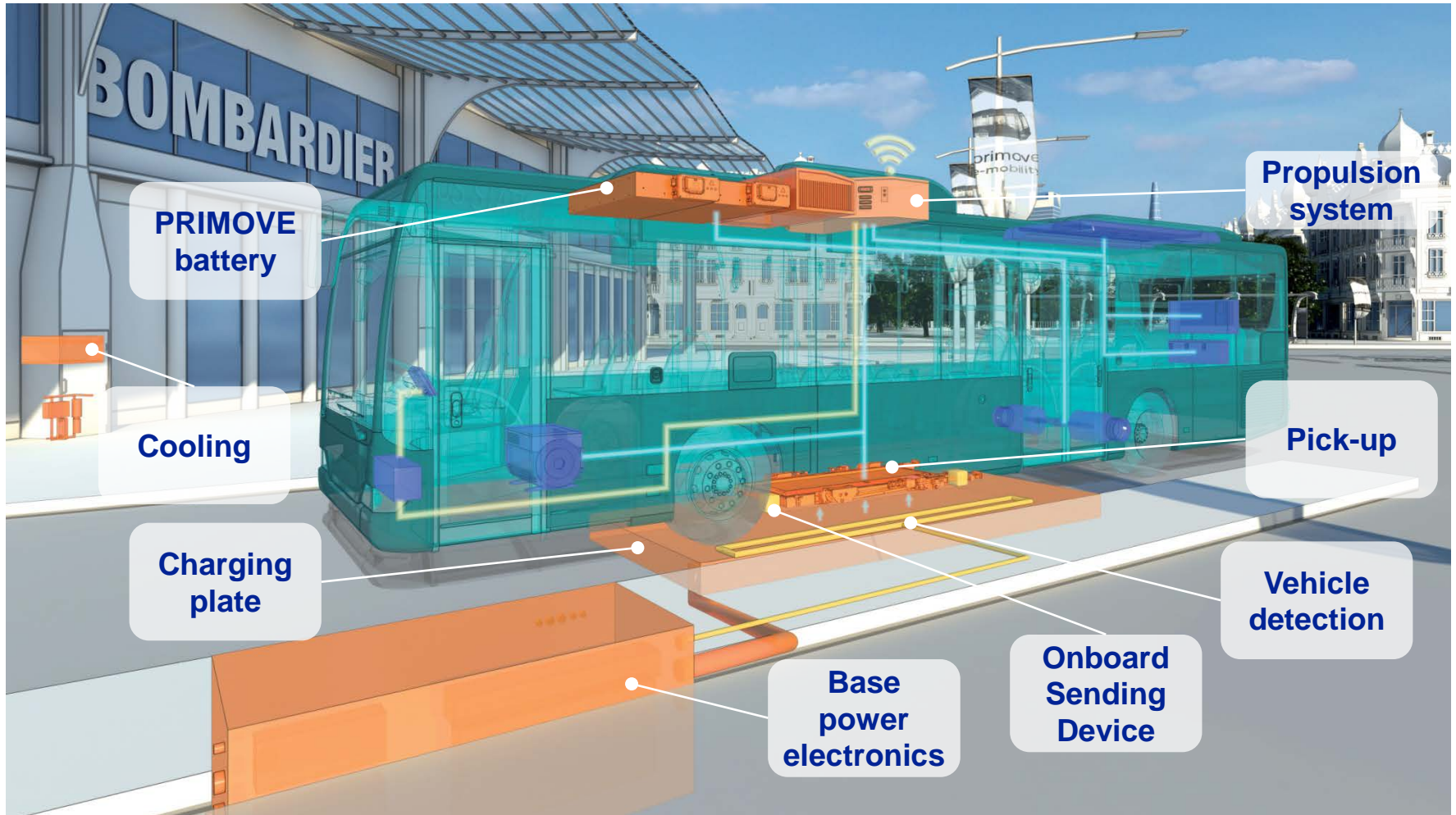
- Reduction of environmental and noise pollution
- Improvement of air quality in cities
- Energy-efficient daily operation

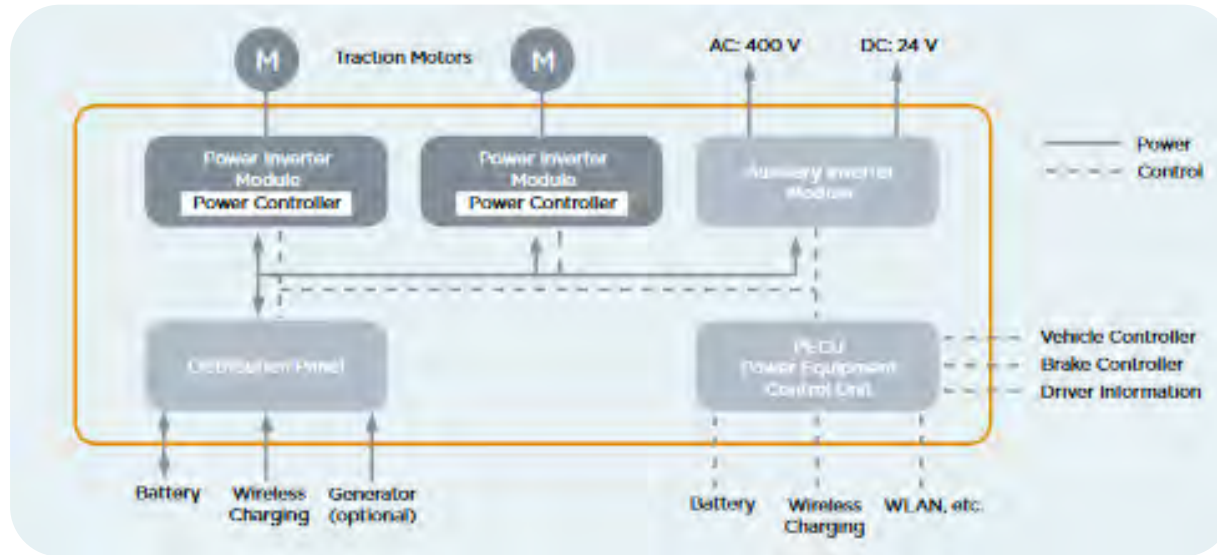




PRIMOVE Package for Electric Mobility

Completely Integrated PRIMOVE E-bus System





Technische Daten der Standardkonfiguration

	Antriebssystem 140-2	Antriebssystem 200-1	Antriebssystem 200-2
Maße (mm)	375 x 1810 x 900	375 x 1810 x 900	375 x 1810 x 900
Gewicht	175 kg	160 kg	200 kg
Zwischenkreisspannung	660 Volt	660 Volt	660 Volt
Antriebsleistung	2 x 140 kW	1 x 200 kW	2 x 200 kW
Heizleistung	1 x 30 kW	1 x 30 kW	2 x 30 kW
Hilfsbetriebeversorgung 400V , AC, 50Hz	2 x 20kVA	2 x 20kVA	3 x 20kVA
Hilfsbetriebeversorgung 24V, DC	10kW (400A)	10 kW (400A)	15 kW (600A)



System Modelling and Validation

Model Based on DYNA4 Commercial Vehicles Product Package

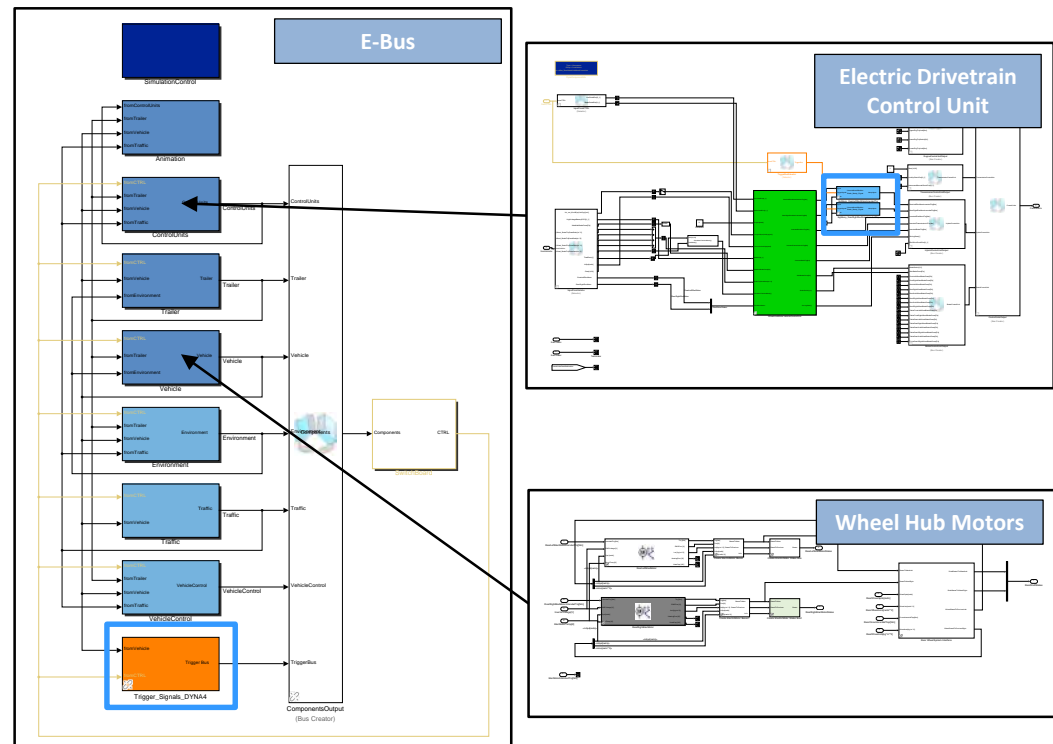
- Framework managed extendable Matlab Simulink model
- Multibody chassis containing axles and steering
- Tire model with the possibility of twin tires at any position

Model Extensions

- Drivetrain replaced by electric wheel hub motors
- E-motor control unit and electrical system
- Parameter driven error injection on motor torques

Parameterisation

- Physical values (mass distribution, E-motor torque curves, ...)
- Typical commercial vehicle characteristic values

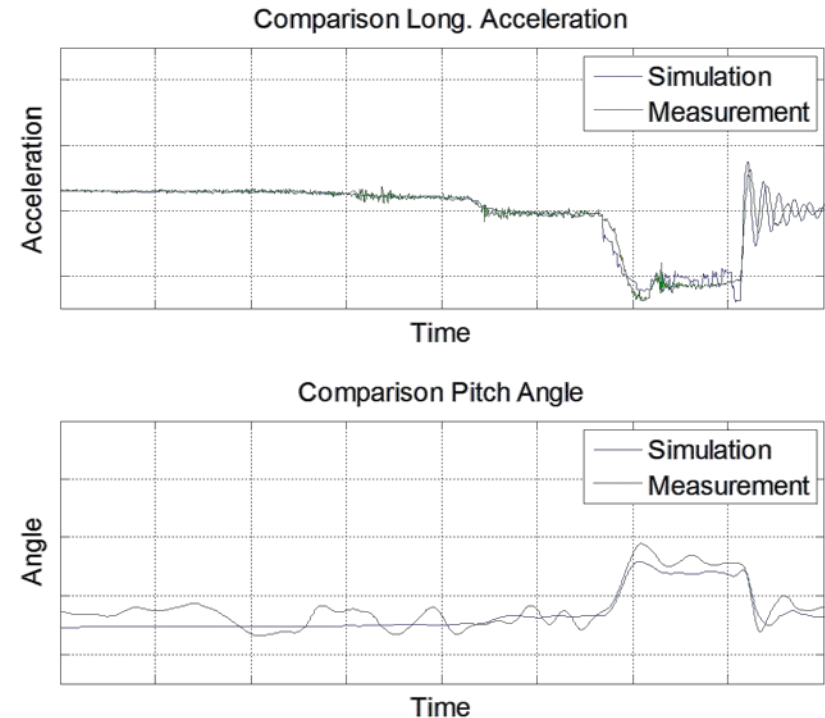


Measurements with Real Vehicle

- Vehicle CAN network trace and additional measurement equipment (differential GPS)
- Standard longitudinal and lateral maneuvers for vehicle dynamics (full acceleration / full brake, steering wheel step, steady state circular driving, ...)
- Error injection with development ECUs / datasets

Validation

- Comparison of characteristic values (e.g. chassis movement)
- Feeding of measurement values into simulation with specific interfaces (e.g. motor torques)
- Sensitivity analysis



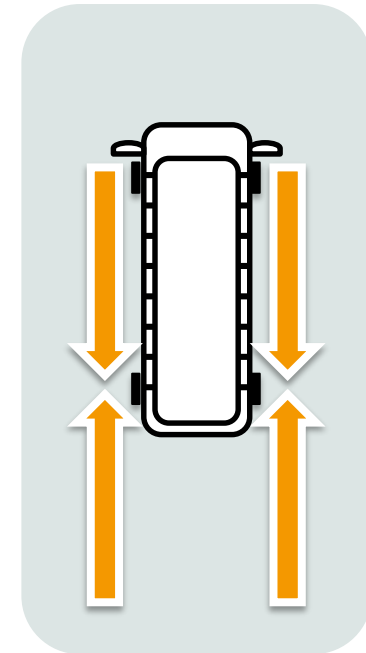


System Simulation and Virtual Driving Maneuver

Example: Erroneous torque on driven wheels

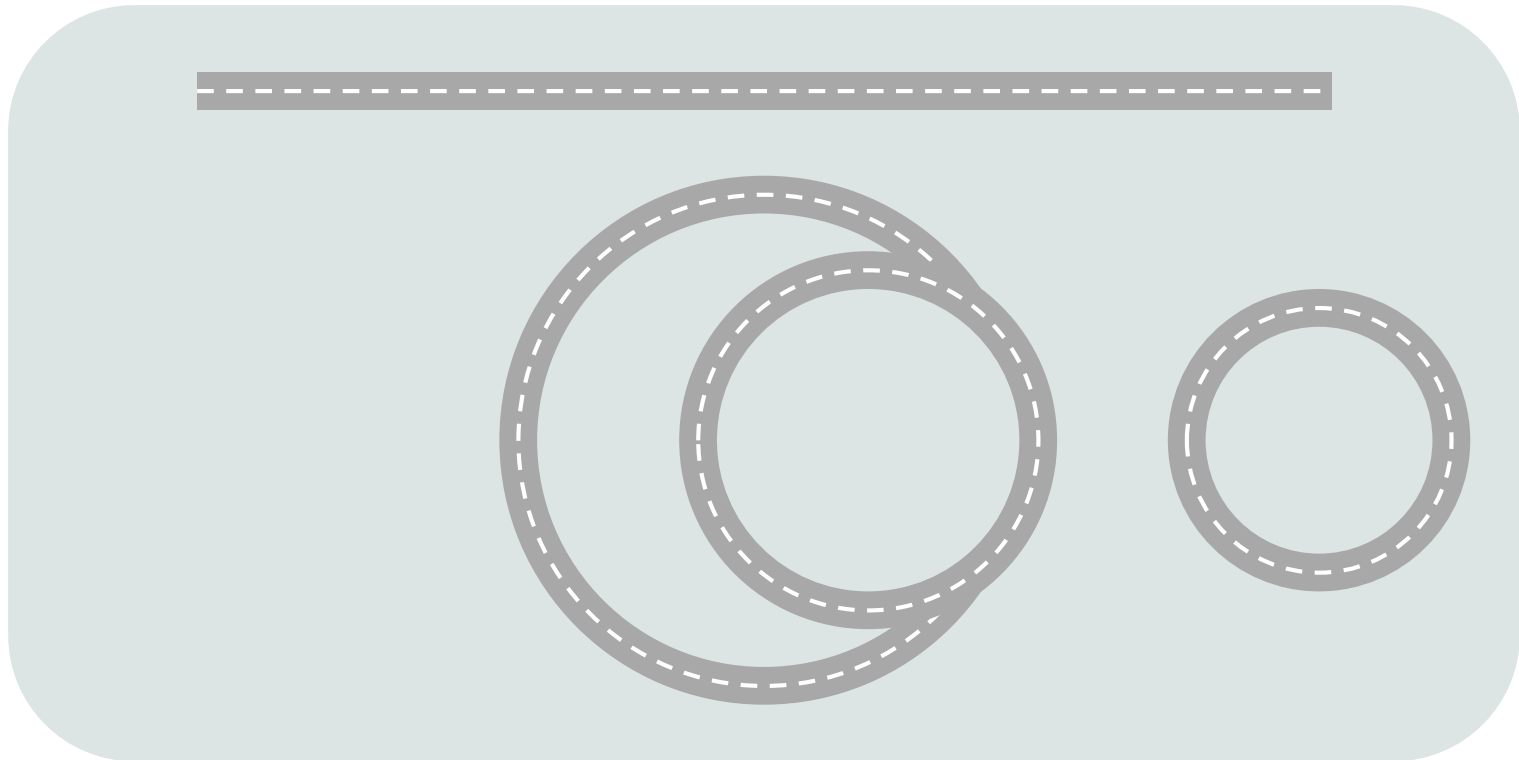
- Identify possible combinations
- Define strength (worst case)
- Torque build up time
- Torque effective time
- ...

No error
Left_Accel_T1_x_y_z
Left_Accel_T2_x_y_z
...
...
...
Left_Brake_T1_x_y_z
Left_Brake_T2_x_y_z
...
...
...
Sync_Accel_T1_x_y_z
Sync_Accel_T2_x_y_z
...
...
...
Sync_Brake_T1_x_y_z
Sync_Brake_T2_x_y_z
...
...
...
Async_T1_x_y_z
Async_T2_x_y_z
...
...
...



Maneuver Definition and Parameter Variation

Example: Define driving maneuver, maneuver parameters, environmental conditions and vehicle variations



Maneuver Definition and Parameter Variation

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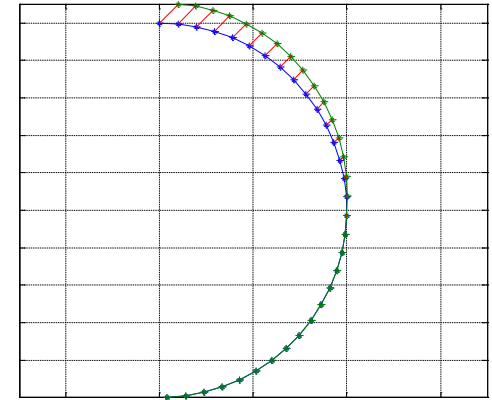
- Different road layouts (e.g. straight line driving, circle driving, ...)
- Simulate with different vehicle speeds (standstill, moving slow, moving fast, ...)
- Variation of road friction (dry, wet, ice, ...)
- Respect different load conditions (empty vehicle, medium load, maximum load, ...)
- ...

Speed 1 [km/h]									Radius 1 [m]									Speed 3 [km/h]								
Friction 1 [-]			Friction 2 [-]			Friction 3 [-]			Friction 1 [-]			Friction 2 [-]			Friction 3 [-]			Friction 1 [-]			Friction 2 [-]			Friction 3 [-]		
Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]	Load 1 [kg]	Load 2 [kg]	Load 3 [kg]			



Post processing - loop through generated results

- Compare signals from reference simulation with error injection simulation
- Comparison logic with user defined Matlab function (e.g. deviation of one- or multidimensional signals)
- Comparison result is added to the result file of the error simulation to enable re-use for further calculations



Calculate characteristic values from signals

- Characteristic value = scalar value for specific time interval
- Characteristic value logic with user defined Matlab function (e.g. maximum, minimum, integral)



Results

- Overview table
- Flat representation of all simulations
- Any number of characteristic values in columns
- Test verdicts (e.g. limit violation) via different cell colours
- Hyperlink to PDF reports

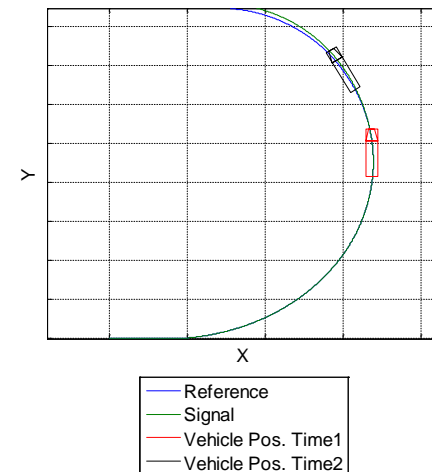
Error Definition	Mass	Speed	Friction	Man. Param. n	Max. Track Deviation t1[ms]	Charac.Value 2	Charac.Value n	Hyperlink
Reference	m1 [t]	v1 [km/h]	$\mu 1$ [-]	...	not available	not available	not available	not available
Definition 1	m1 [t]	v1 [km/h]	$\mu 1$ [-]	...	0,00	...	...	Report 1.pdf
Definition 2	m1 [t]	v1 [km/h]	$\mu 1$ [-]	...	0,00	...	...	Report 2.pdf
Reference	m2 [t]	v1 [km/h]	$\mu 1$ [-]	...	not available	not available	not available	not available
Definition 1	m2 [t]	v1 [km/h]	$\mu 1$ [-]	...	0,00	...	...	Report 3.pdf
Definition 2	m2 [t]	v1 [km/h]	$\mu 1$ [-]	...	0,00	...	...	Report 4.pdf
Reference	m1 [t]	v2 [km/h]	$\mu 1$ [-]	...	not available	not available	not available	not available
Definition 3	m1 [t]	v2 [km/h]	$\mu 1$ [-]	...	0,05	...	...	Report 5.pdf
Definition 3	m1 [t]	v2 [km/h]	$\mu 1$ [-]	...	0,05	...	...	Report 6.pdf
Definition 1	m1 [t]	v2 [km/h]	$\mu 1$ [-]	...	0,02	...	...	Report 7.pdf
Definition 2	m1 [t]	v2 [km/h]	$\mu 1$ [-]	...	0,02	...	...	Report 8.pdf
Reference	m2 [t]	v2 [km/h]	$\mu 1$ [-]	...	not available	not available	not available	not available

Reference	m2 [t]	v3 [km/h]	$\mu 3$ [-]	...	not available	not available	not available	not available
Definition 1	m2 [t]	v3 [km/h]	$\mu 3$ [-]	...	0,02	...	...	Report n.pdf
Definition 2	m2 [t]	v3 [km/h]	$\mu 3$ [-]	...	0,02	...	...	Report n+1.pdf

Reports

- One report per error simulation
- Any number of diagrams, tables, ... for selected signals
- Path to result mat file

Trajectory Comparison Reference vs. Error-Simulation



Project Results: Some Videos

Measurements



Simulations



Conclusion

- System „electrical city bus“ successfully modelled and validated
- Extendable test plan can be simulated and interpreted automatically
- Driving test & simulation in combination as basis for assessment, implementation and parameterisation of safety functions

Outlook

- System variants (drivetrain, chassis)
- Human reaction (driver model, driver-in-the-loop)

