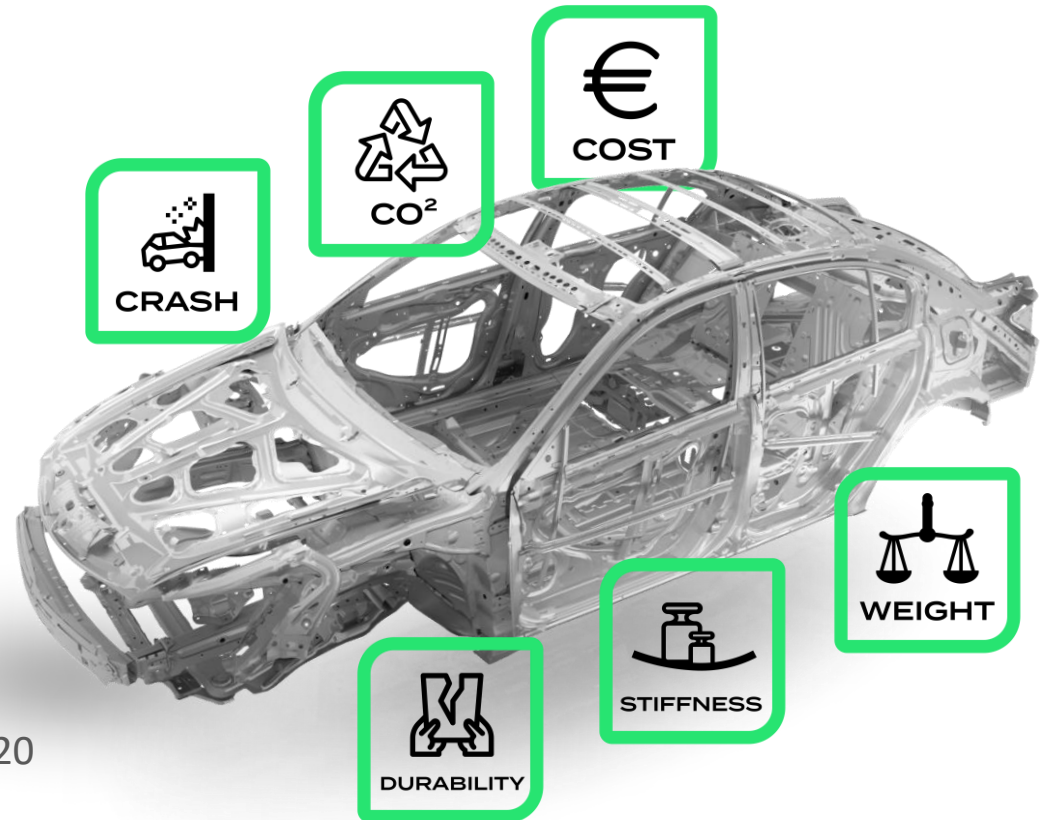


# LWR – Lightweight Rating of Vehicle Body Structures



**LWR-Soft**  
Lightweight Rating



**Conference:** Strategies in Car Body Engineering 2020

**Location:** Bad Nauheim

**Date:** 4<sup>th</sup> – 5<sup>th</sup> March 2020

**Contact:** Prof. Dr.-Ing. Thilo Röth  
M.Sc. Sebastian Esser, MBA

# Project-Background

The Project has been mainly performed with the research funding of the German Ministry BMWi (Bundesministerium für Wirtschaft und Energie) within the Research Subject „Light Weight Concepts for Vehicles on Roads and Rails“. The Project Execution Organization was the TÜVRheinland.

Project Name: „LeiRa“ – Leichtbau-Rating-System für Karosserie- und Fahrwerkstrukturen

Cooperation-Partner:

- Ford Werke GmbH
- Imperia GmbH / FEV Vehicle GmbH
- FH Aachen

The shown results are mainly derived by the research activities of the FH Aachen (University of Applied Sciences)!

**imperia**  
AUTOMOTIVE ENGINEERING

**FEV**

Projektträger

 **TÜVRheinland®**  
Genau. Richtig.



Fördergeber



Bundesministerium  
für Wirtschaft  
und Energie

Programm: Leichtbaukonzepte für  
Straßen- und Schienenfahrzeuge

# We are Living in a World of Rating Systems

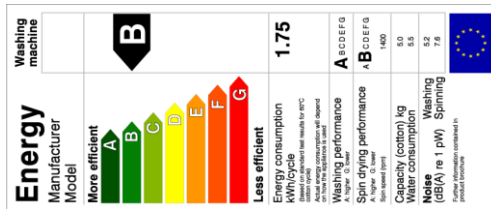
## Why do we use Rating Systems?

To get a quick and „objective“ judgment of the functional performance of a product!

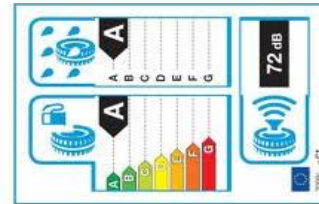
## Where do we use Rating Systems for Example?



Crash



Energy-Consumption



Tires



Food

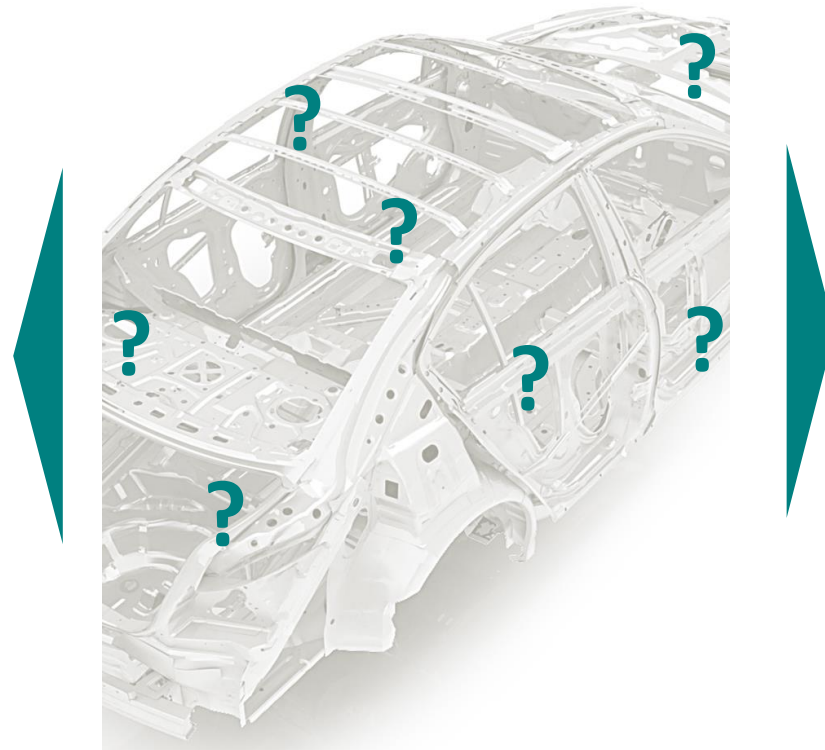
## What is behind Rating Systems?

Detailed functional criteria or sub-criteria are getting judged on the bases of standardized tests. Typically the Weighting and the Balancing Method (or both together) are used to define a set of rating criteria.

# To Judge Many Thousands of Different Body Structures a Light Weight Rating System need to Focus on the Objective Comparison of Vehicle Functions, resp. the Structural Functions



Rating Main Criteria



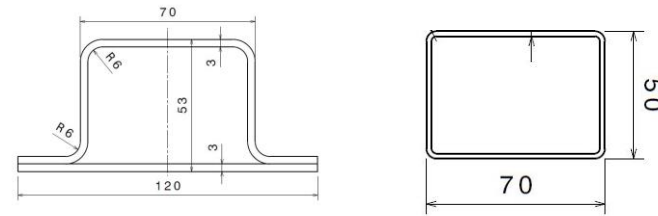
**The Question is:** What Lightweight Technology is at what location in a new BIW the best?

- **Materials**
- **Design Principals**
- **Joining**
- **Manufacturing**

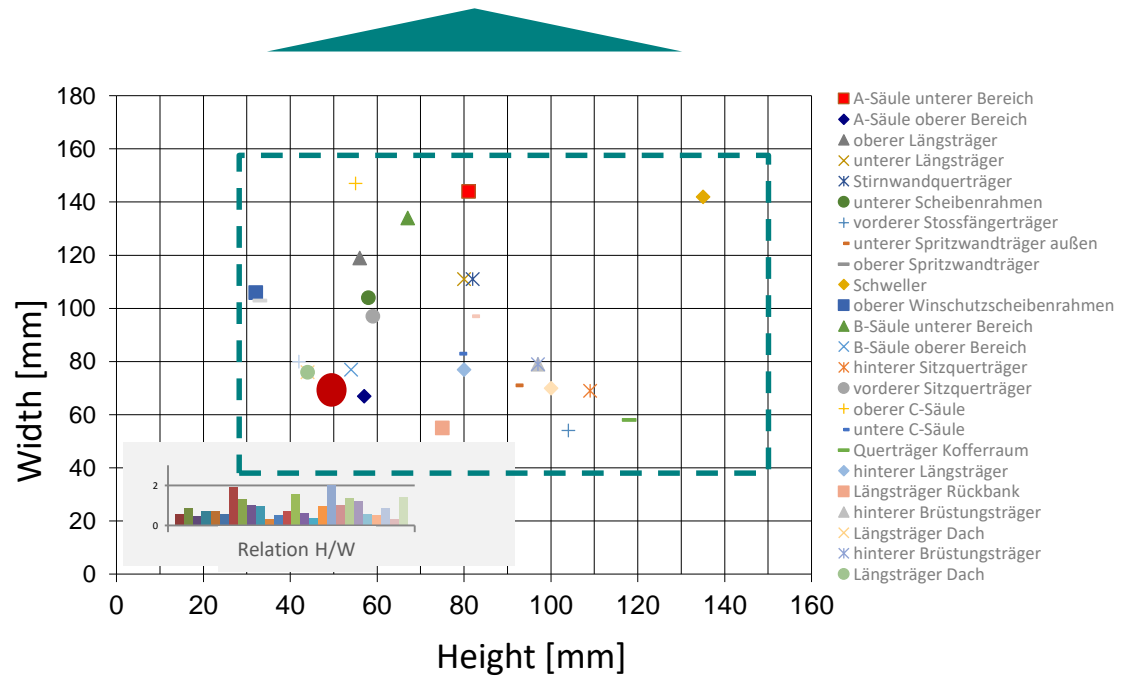
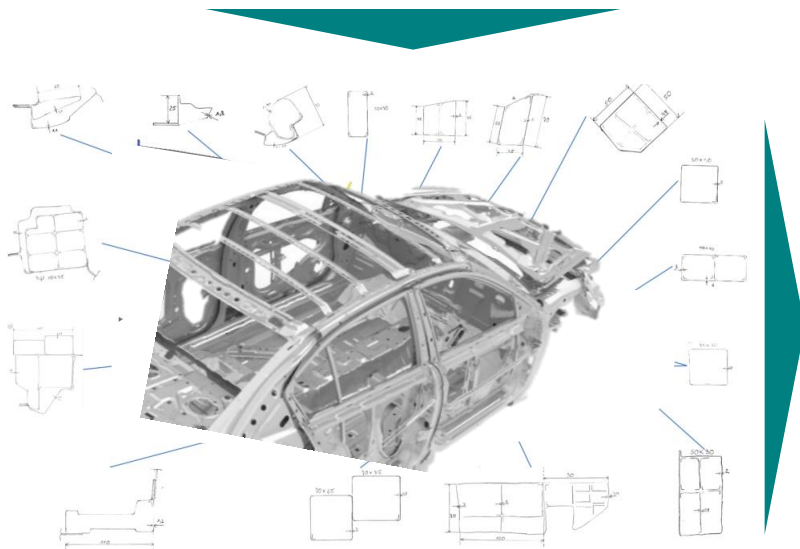
Thousands of Combinations to Design Body Structures!

# The Baseline of LWRating is a fixed defined Geometry of a Structure, which has been Derived from Vehicle Body Structures Benchmark

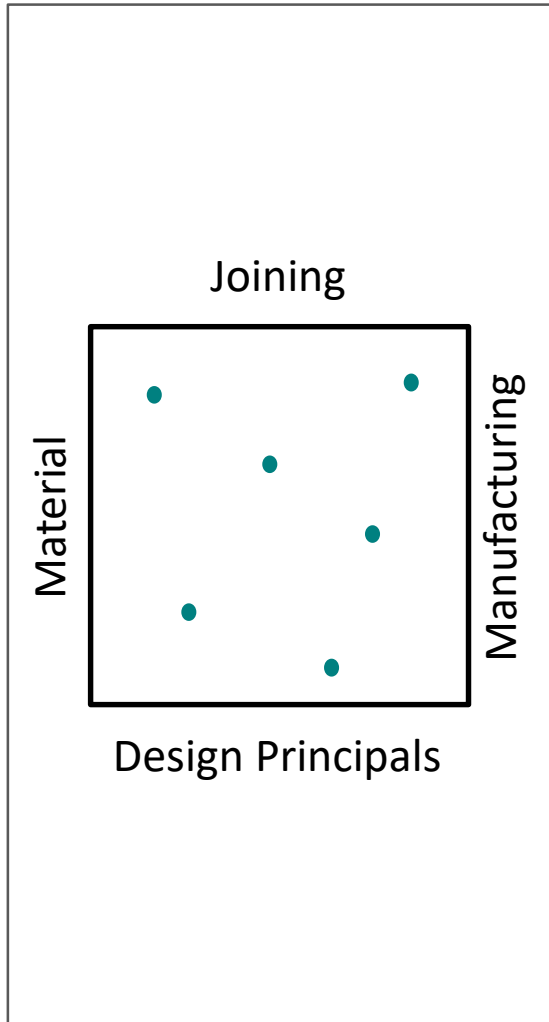
What is the right Space for the Reference Structure?




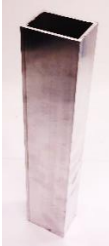




Length: 370mm



# A Selection of State of the Art Structures and Future Structures have been used to validate the LWRating



			
	<b>Stamping</b>	<b>Stamping</b>	<b>Rollform</b>
<b>Weight [kg]</b>	0,98	0,95	1,27
<b>Material</b>	Steel (ZSTE 340)	Alu (AW 5083)	Steel (ST37-2)
<b>Gauge [mm]</b>	1,0	3,0	2,0
<b>Joining</b>	weld spots & Bond	Semi-tub. rivet & bond	-
			
	<b>Extrusion</b>	<b>Vacuum Infusion</b>	<b>3D-Printing</b>
<b>Weight [kg]</b>	0,88	0,48	0,90
<b>Material</b>	Alu (AW 6060)	CFK (KDK 8004)	Alu (AlSi10Mg)
<b>Gauge [mm]</b>	4,0	2,6	-
<b>Joining</b>	no	M5 Bolt & nut & bond	no

# Based on the Weighting Method, LWRating assesses Lightweight Construction at 3 levels

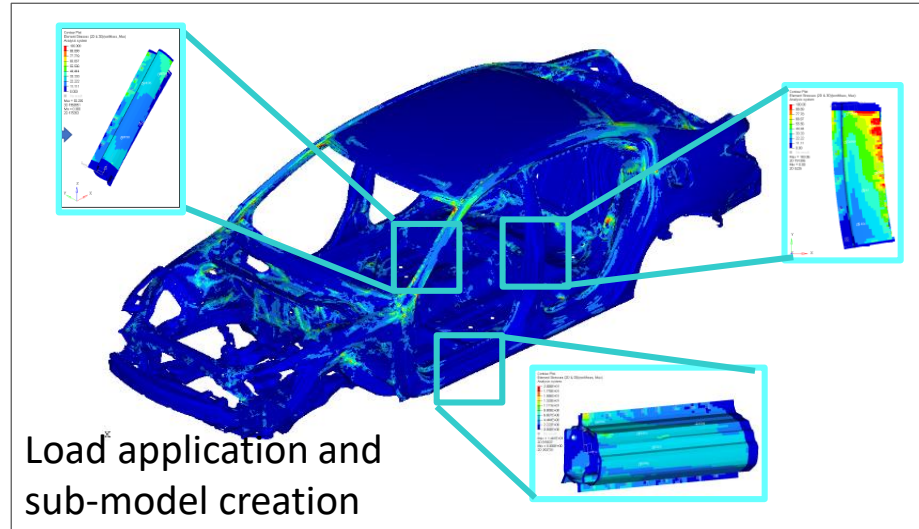
<b>Level 1</b> Overall result				
<b>Level 2</b> Per performance criterion	Stiffness / NVH 	Crash 	Durability 	Sustainability/CO <sub>2</sub> 
<b>Level 3</b> Detailed review per load case	<p><b>Stiffness</b> (2 Factors)</p> <p>2 x 3 tests</p>	<p><b>Crash</b> (11 Factors)</p> <p>4 x 3 tests</p>	<p><b>Durability</b> (3 Factors)</p> <p>15-18 tests</p>	<p><b>Sustainability</b> (3 Factors)</p> <p>3 Analysis</p>

Like any other rating system, the LiRa rating scheme is evolutionary!

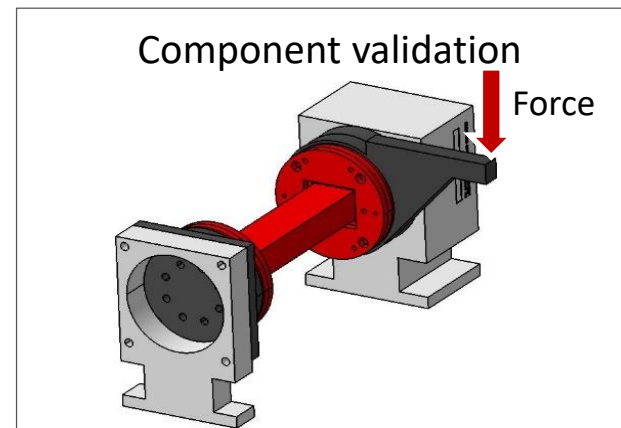
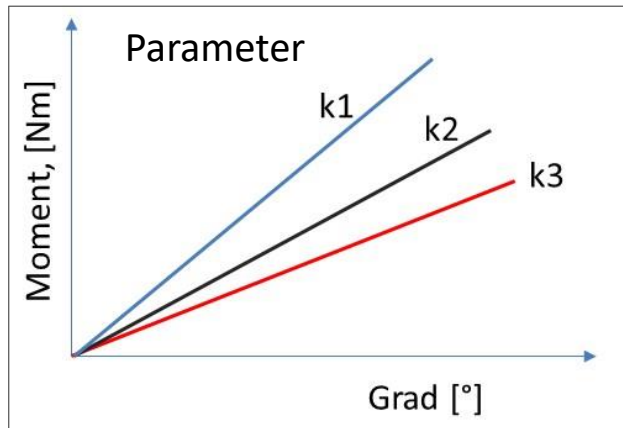
# Based on the overall Vehicle Analysis the Stiffness Load Case and the Stiffness Parameter are derived



Determination of driving dynamics as input for body model



Load application and sub-model creation

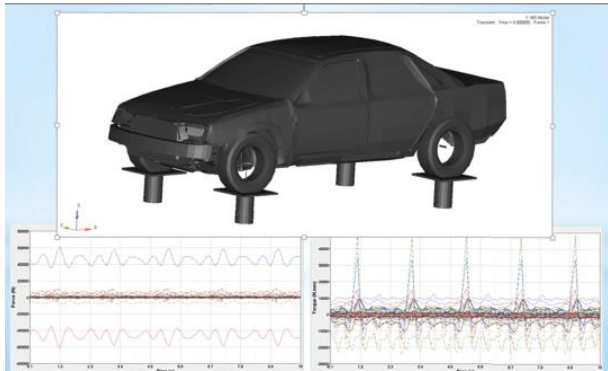


1 Loadcase  
1 Parameter

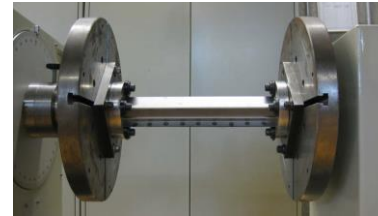




# Based on the overall Vehicle Analysis the Operational Strength Load Case and the Durability Parameter are derived



Analysis of real driving load conditions of structures



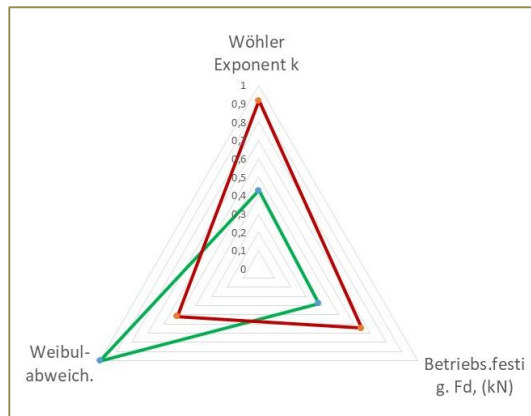
Torsion load



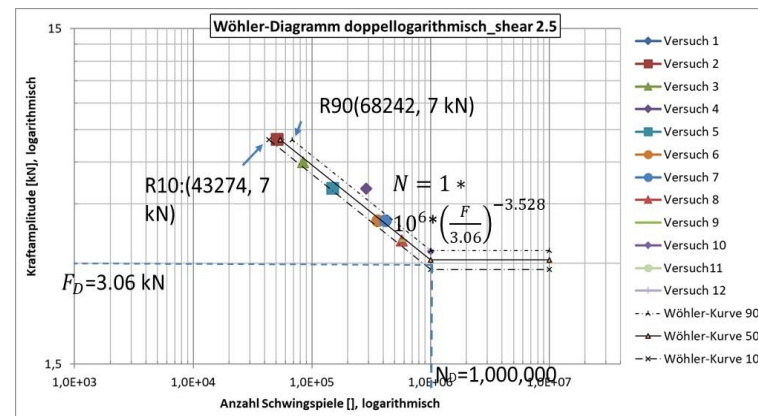
4-Point-Bend

## Load Cases - Definition

1 Load case  
6 Force levels  
3 Parameters



Parameters



Component – Woehler – Curve



# Process for determining the CO<sub>2</sub> Parameter on the basis of Reference Data and the help of a LWRating CO<sub>2</sub> evaluation Method

EU body and vehicle benchmark to define the reference base

Application on LWRating technologies

**Data – Starting Base**

**Production**  
(Using Software GABI in Cooperation with EDAG GmbH)

**Driving Operation**  
(WLTP)

**Recycling**  
(Materials)

**Own LWRating-CO<sub>2</sub>-Method**

**Gesamt-CO<sub>2</sub>-Bilanz [kg]**

	Herstellung	Betrieb	Recycling	Total	
P001	2,3	-0,80	-0,40	1,10	★
P002	7,19	23,39	2,25	32,83	★★★★★
P003	28,77	22,27	2,66	53,70	★★★★★
P004	8,79	30,47	2,95	42,21	★★★★★
P005	21,34	21,08	2,46	44,88	★★★★★

**Legende (jew. Bestwert/Total)**

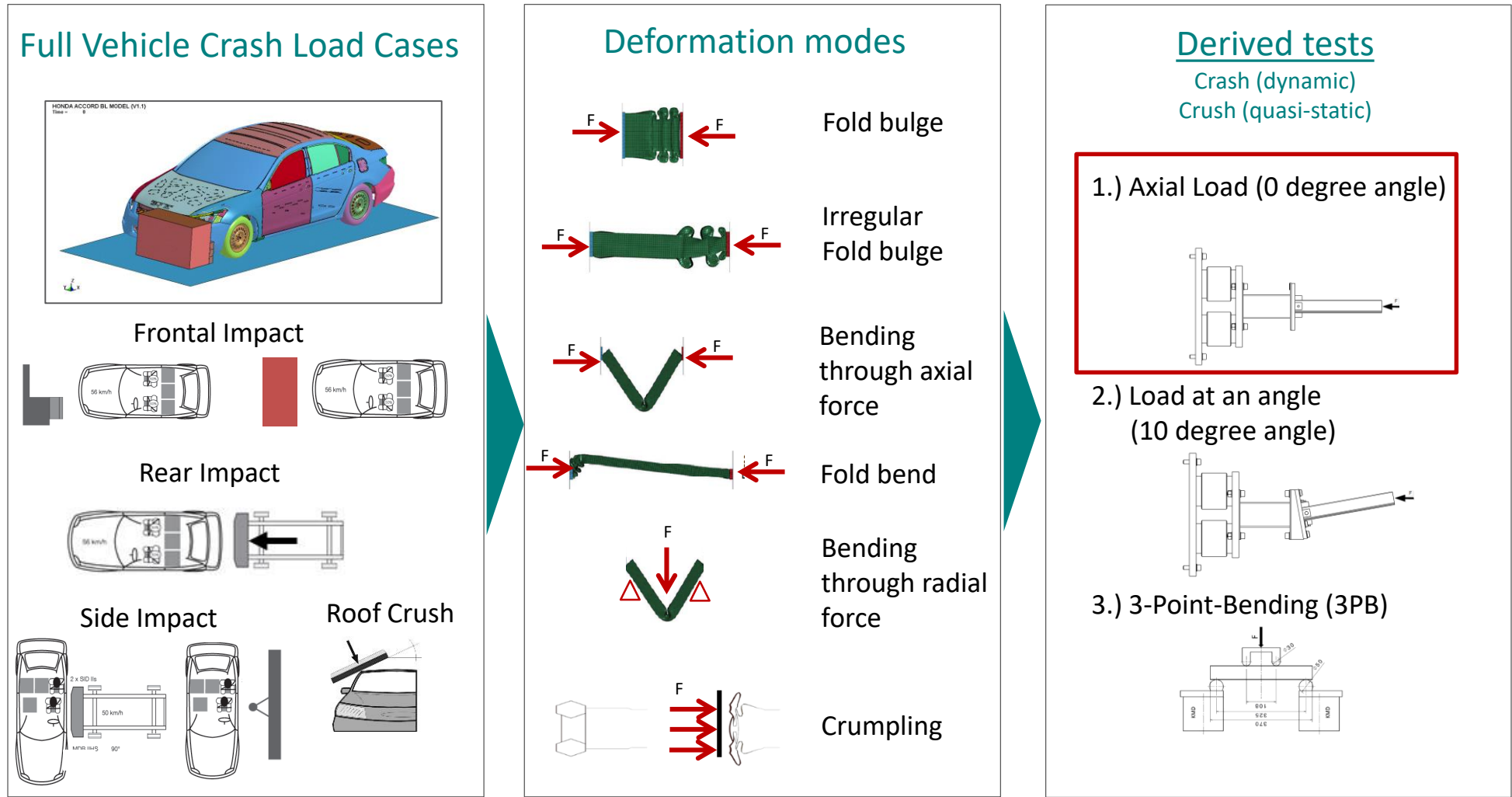
- 0-0,5 ★
- 0,5-0,6 ★★
- 0,6-0,7 ★★★
- 0,7-0,8 ★★★★
- 0,8-1 ★★★★★

LWRating - CO<sub>2</sub>-Parameter

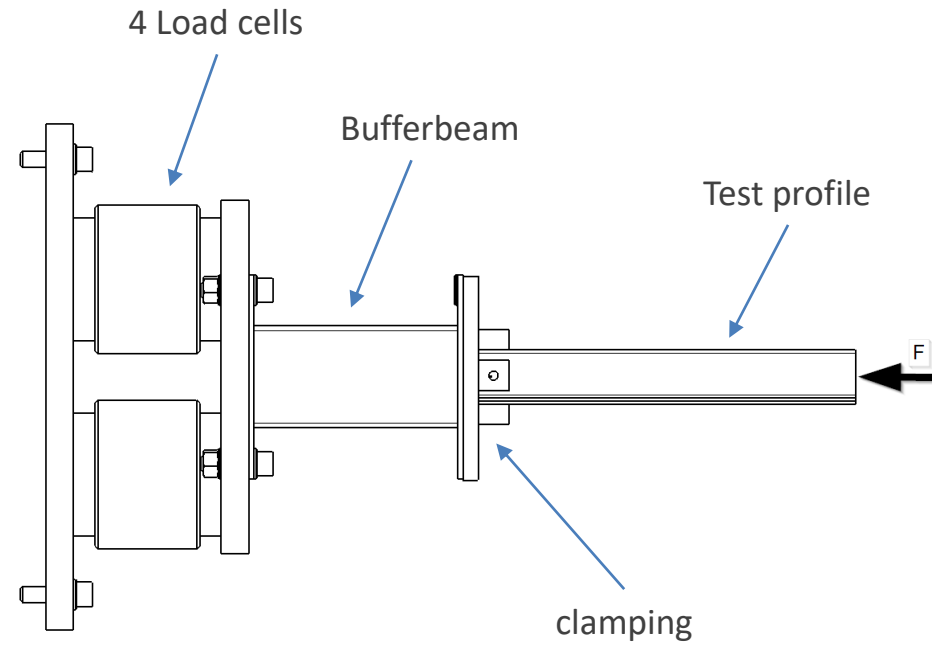
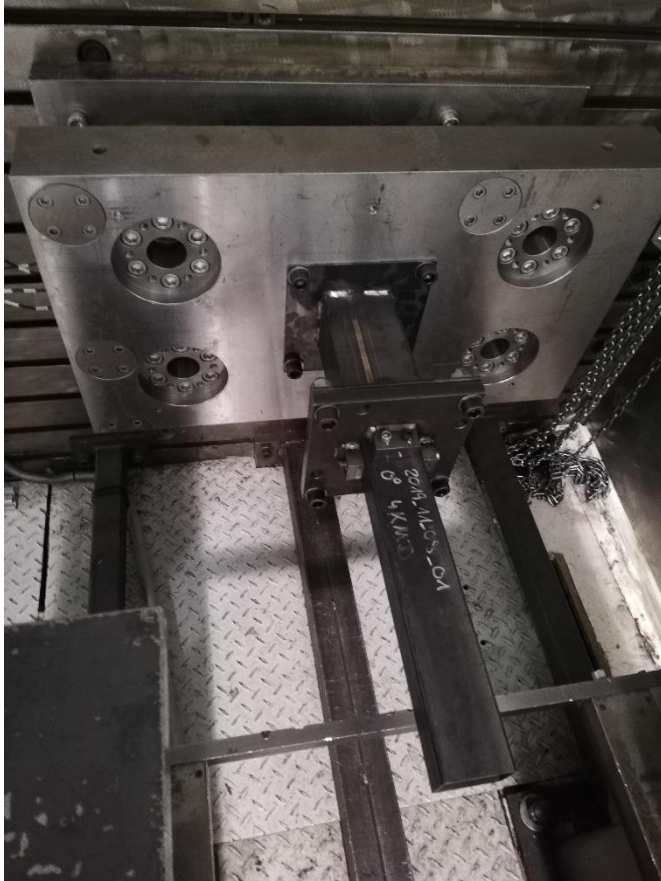
3 Parameters



# Based on the complete Vehicle Simulations and Deformation modes the LWRating Crash Tests are derived



# Final exemplary Test Setup for the High-Speed Crash Load Case under 0° and 60 kph



Speed: 60 kph  
Mass sledge: 350 kg



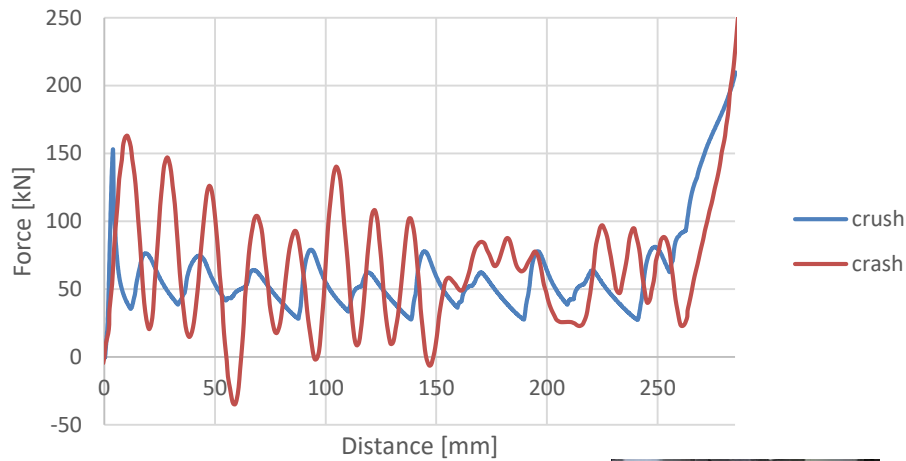
# Comparison of High-Speed Crash and quasi-static Crush for an exemplary LWRating Profile

Steel Rectangle

**Axial Load 0° Angle**

Aluminum Rectangle

TP004 Comparison dynamic & quasi-static

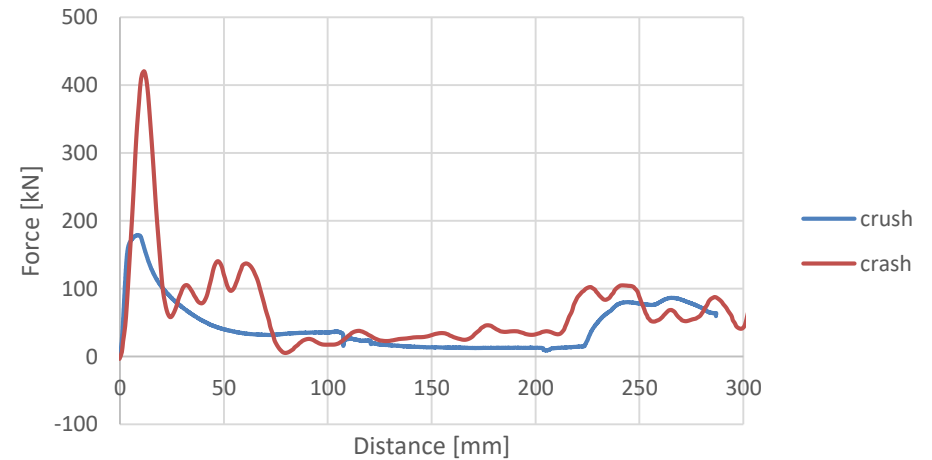


Crash / 60kph



Crush / 1mm/s

TP005 Comparison dynamic & quasi-static



Crash / 60kph



Crush / 1mm/s



# Test procedure for the Crash Load Case – From Test planning to Parameter Evaluation

**TP002**  
ZSTE 340, 0.975 kg

**TP003**  
AW 5083, 0.950 kg

**TP004**  
ST 37-2, 1.274 kg

**TP005**  
AW 6060, 0.880 kg

**TP006**  
CFK, 0.480 kg

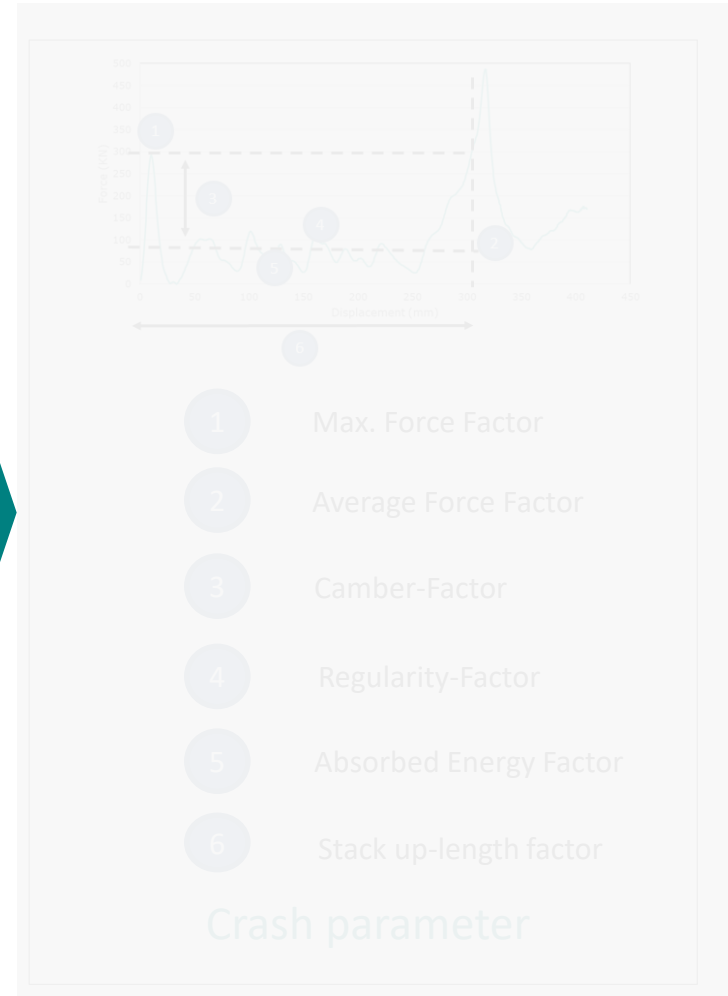
**TP007**  
AlSi10, 0.900 kg

Pos. Nr.	Funktion	Kurzbeschreibung	TP001	TP002	TP003	TP004	TP005	TP006	TP007	TP008
			D-U	St-Hut	Al-Hut	St-4K	Al-4K	CFK	3D-Druck	St-R
1	LiRa_01_C A	Crash		3	3	3	3	3	3	2
2	LiRa_02_C A	Crash		3	3	3	3	3	3	2
3	LiRa_03_C A	Crash		3	3	3	3	3	3	
4	LiRa_04_C A	Crash		3	3	3	3	3	3	
5	LiRa_05_C U	Crash		5	5	7	6	3	2	
6	LiRa_06_C U	Crash		5	3	6	4	3	2	
7	LiRa_07_C U	Crash		3	3	3	3	3	3	
8	LiRa_08_C U	Crash		3	3	3	3	3	3	
9	LiRa_09_ST	Steifigkeit		2	2	2	2	2	2	
10	LiRa_10_ST	Steifigkeit		2	2	2	2	2	2	1
11	LiRa_11_ST	Steifigkeit		2	2	2	2	2	2	0
12	LiRa_12_B	Betriebsfestigkeit		15	15	15	15			10
13	LiRa_13_C O	CO2 / Anschauung		0	0	0	0	0	0	

Trial program and test subjects TP2-7

- Force-displacement curves
- Standardized images
- Standardized films

Creation of standard based test data



# A look at the result Table, which is input for LWR-Software, serves as an example of a single Crash Load Case



Model	Vehicle ID	Mass (kg)	Inertia (kgm²)	Restraint Type	Max Force (kN)	F <sub>20%</sub>	Max Force Factor (F <sub>max</sub> )	Max Force Factor (F <sub>10%</sub> )	Average Force (F <sub>avg</sub> )	F <sub>20%</sub>	Average Force Factor (F <sub>avg</sub> )	Average Force Factor (F <sub>10%</sub> )	Length	Stack-up Length (S <sub>1</sub> )	Stack-up Length (S <sub>2</sub> )	Energy Absorbed (E <sub>abs</sub> )	Energy Absorbed (E <sub>abs</sub> )	Crash Factor (C)	Regularity Factor (R)	CRF <sub>10%</sub>				
TP007	01	950	0	Druck/Schwingung	123,20	0,250	1,227	0,500	139,301	0,155	1,395	0,622	14,500	360,000	0,400	0,110	40,000	2028,563	2,254	0,301	0,825	0,300	0,930	
Minilevante TP 807 0 Grad							1,227				1,395					0,110		0,301	0,825	0,300	0,930			
TP008	01	950	0	Frontal	93,416	0,332	1,000	0,844	46,771	0,085	1,005	0,340	319,893	29,307	0,042	1,133	4,369	1944,314	27,171	1,223	0,302	0,256	0,604	0,385
Minilevante TP 808 0 Grad							1,000				1,005					1,133		1,223	0,302	0,256	0,604	0,385		
TP009	01	950	0	Seitlich	179,301	0,203	0,300	0,407	44,704	0,051	0,550	0,203	297,005	170,000	0,193	0,246	19,318	12947,553	14,539	0,657	0,362	0,250	0,300	0,480
TP020	02	950	0	Seitlich	169,086	0,191	0,320	0,382	39,307	0,045	0,573	0,191	298,621	170,000	0,193	0,246	19,318	10842,327	12,894	0,544	0,134	0,237	0,300	0,430
TP005	05	950	0	Seitlich	90,558	0,208	1,000	0,415	44,305	0,050	0,643	0,201	273,736	170,000	0,193	0,246	19,318	12130,474	15,785	0,620	0,163	0,243	0,300	0,475
Minilevante TP 805 0 Grad							0,367				0,624					0,246		0,607	0,243	0,300	0,464			
TP004	01	1274	0	Fahrerseitig																				
TP004	02	1274	0	Fahrerseitig	63,962	0,100	0,573	0,240	50,208	0,044	0,583	0,170	271,574	68,426	0,054	0,393	5,371	6294,008	11,361	0,539	0,133	0,387	0,603	0,590
TP004	03	1274	0	Fahrerseitig	73,402	0,141	0,673	0,262	58,903	0,046	0,583	0,193	278,388	61,034	0,048	0,391	4,936	10197,355	12,744	0,572	0,141	0,324	0,600	0,633
TP004	04	1274	0	Fahrerseitig	93,132	0,144	0,693	0,287	61,860	0,048	0,613	0,192	279,558	60,442	0,047	1,000	4,744	17037,643	13,420	0,604	0,149	0,334	0,706	0,656
Minilevante TP 804 0 Grad							0,650				0,587					0,395		0,572		0,342	0,676	0,630		
TP003	01	950	0	Fahrerseitig	104,500	0,163	0,704	0,325	74,253	0,078	1,000	0,313	248,257	31,743	0,097	0,491	6,657	10408,885	15,441	0,675	0,236	0,481	0,705	0,723
TP003	02	950	0	Fahrerseitig	93,446	0,174	0,639	0,340	73,534	0,077	0,989	0,310	248,785	32,225	0,056	0,947	5,602	2105,641	22,236	1,000	0,247	0,445	0,733	0,610
Minilevante TP 803 0 Grad							0,311				0,395					0,665		0,338		0,463	0,722	0,706		
TP002	01	975	0	Fahrerseitig	48,673	0,050	0,100	0,100	21,839	0,022	0,296	0,090	279,338	90,862	0,062	0,763	6,222	6100,187	6,257	0,292	0,070	0,449	0,701	0,450
TP002	02	975	0	Fahrerseitig	77,703	0,080	0,304	0,159	26,700	0,027	0,358	0,110	290,374	49,626	0,051	0,332	5,990	7752,364	7,352	0,359	0,088	0,344	0,730	0,510
Minilevante TP 802 0 Grad							0,310				0,310					0,947		0,328		0,396	0,719	0,485		

Input Parameters	Weighting factors
Best Ende: 0,207532	Max force weightage (w1)
Best Ende: 0,079390	Average force weightage (w2)
Best Side: 0,047442	Stack-up length weightage (w3)
Best: 0,271686	Absorbed Energy weightage (w4)
	Crash weightage (w5)
	Regularity weightage (w6)

Crashworthiness factor (CWF) = (MaxF + AvgF + Eavg + Lavg + Ravg)/50

Crashworthiness factor (CWF2) = (M+w1 + A+w2 + E+w3 + L+w4 + R+w5)/50

CRF = CWF\*1000/m

### Equations

$$CWF_{Max} = \frac{(F_{max10\%} \cdot w_1) + (F_{d10\%} \cdot w_2) + (S_{10\%} \cdot w_3) + (E_{abs10\%} \cdot w_4) + (C \cdot w_5) + (R \cdot w_6)}{60}$$

$$CWF_{Avg} = \frac{(F_{max50\%} \cdot w_1) + (F_{d50\%} \cdot w_2) + (S_{50\%} \cdot w_3) + (E_{abs50\%} \cdot w_4) + (C \cdot w_5) + (R \cdot w_6)}{60}$$

1) Average Force Factor (F<sub>avg</sub> / L<sub>avg</sub>)

$$F_{avg} = \frac{F_{max}}{L_{avg}} + \frac{F_{20\%}}{L_{20\%}}$$

$$F_{avg} = \frac{F_{max}}{L_{avg}} + \frac{F_{20\%}}{L_{20\%}}$$

Formula 1.3: Average Force Factor

2) Stack-up Length Factor (S<sub>1</sub> / S<sub>2</sub>)

$$S_{10\%} = \frac{S_{10\%}}{L_{10\%}} + \frac{S_{20\%}}{L_{20\%}}$$

$$S_{10\%} = \frac{S_{10\%}}{L_{10\%}} + \frac{S_{20\%}}{L_{20\%}}$$

Formula 1.4: Stack-up Length Factor

3) Absorbed Energy Factor (E<sub>abs10%</sub> / E<sub>abs50%</sub>)

$$E_{abs10\%} = \frac{E_{abs10\%}}{L_{10\%}} + \frac{E_{abs20\%}}{L_{20\%}}$$

$$E_{abs50\%} = \frac{E_{abs50\%}}{L_{50\%}} + \frac{E_{abs10\%}}{L_{10\%}}$$

Formula 1.5: Absorbed Energy Factor

4) Crash Factor (C)

$$C = \frac{E_{abs}}{E_{avg}}$$

Formula 1.6: Crash Factor

5) Regularity Factor (R)

$$R = \frac{d(10)}{d(20)}$$

Formula 1.7: Regularity Factor

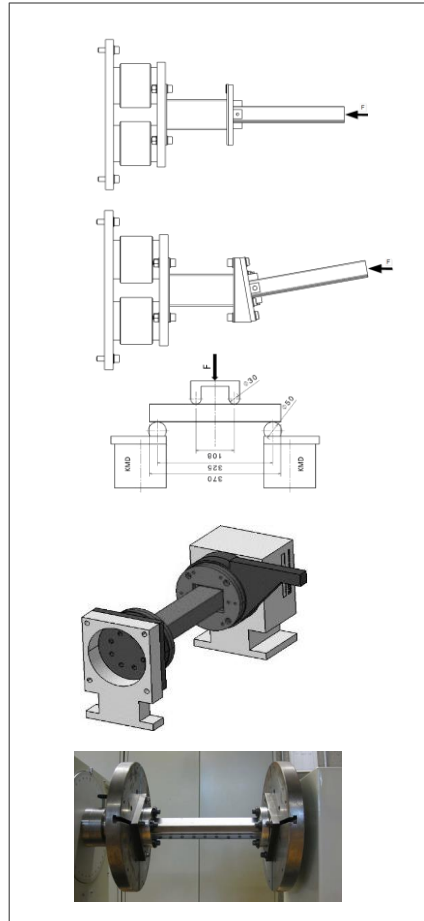
3 x 3 Tests  
3-6 Parameter  
Depending on Deformation Mode!

LWR-Software

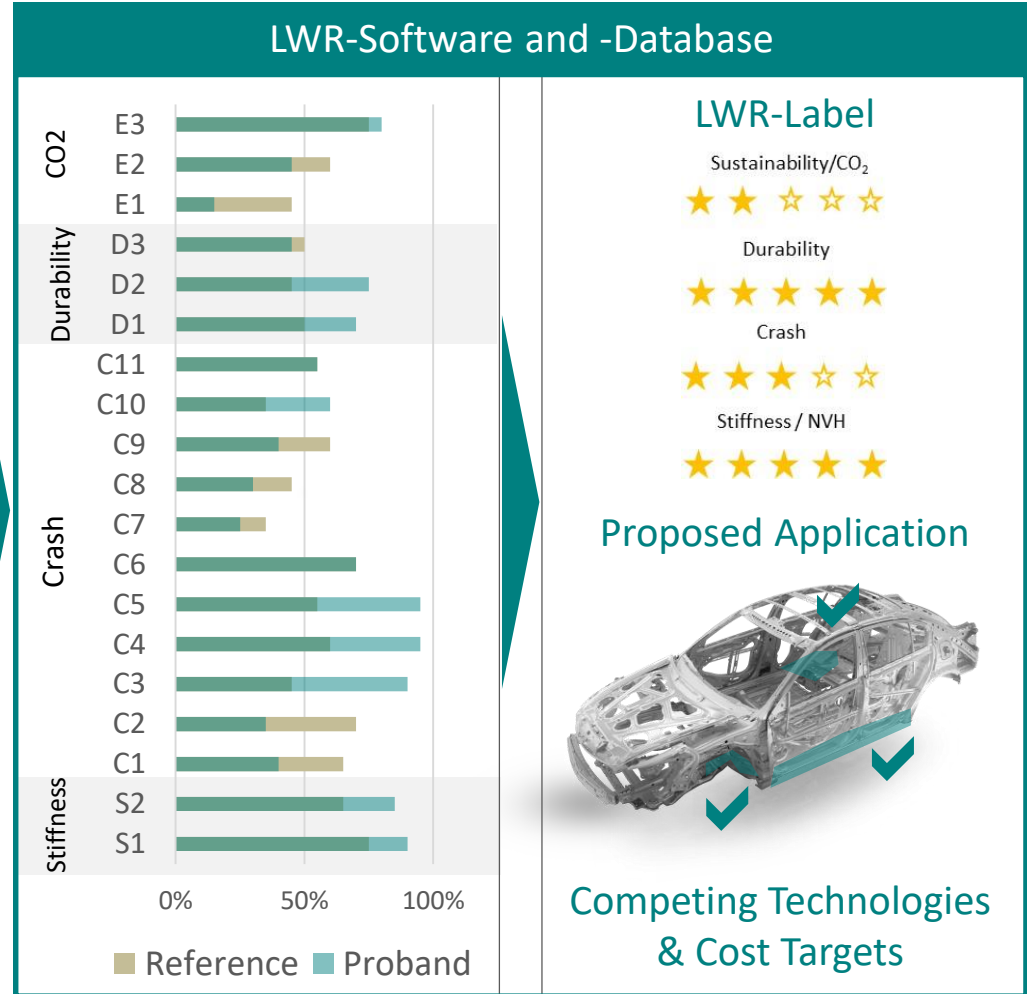
# Scenario 1 - How to Use LWRating? A new Technology will be rated and according the rating results the best possible Areas will be proposed!



New Technology



Testing & Analysis

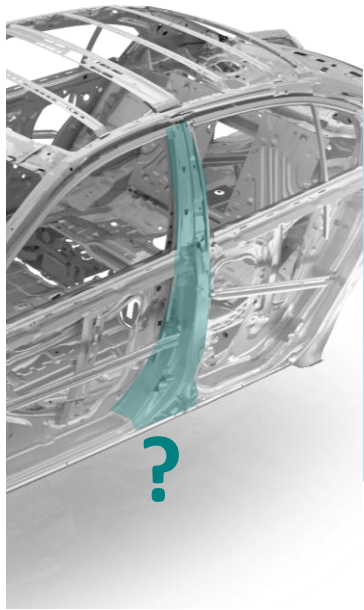


Functional Performance

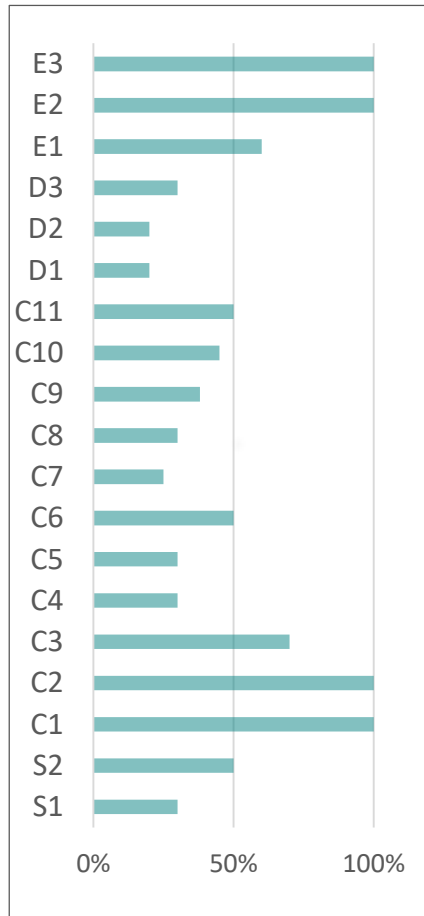
Output-Data



# Scenario 2 - How to Use LWRating? You are interested in an Area of a Body Structure and you want to know, which Technology is the best for it!



Application Area



Functional Targets

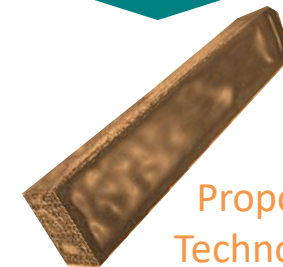
### LWR-Software and -Database

Material	Profile	Manufacturing	Weight [kg/m]	Yield strength [N/mm²]	Tensile strength [N/mm²]	Elongation at break [%]	Modulus of elasticity [N/mm²]
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000
AluSi	AluSi	Hot Rolled	14,07	210	270	12	70000

Technology	S1	S2	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	D1	D2	D3	E1	E2	E3
S1	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
S2	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C1	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C2	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C3	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C4	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C5	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C6	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C7	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C8	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C9	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C10	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
C11	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
D1	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
D2	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
D3	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
E1	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
E2	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100
E3	25	50	100	100	65	35	35	50	30	35	40	45	50	20	25	35	65	100	100

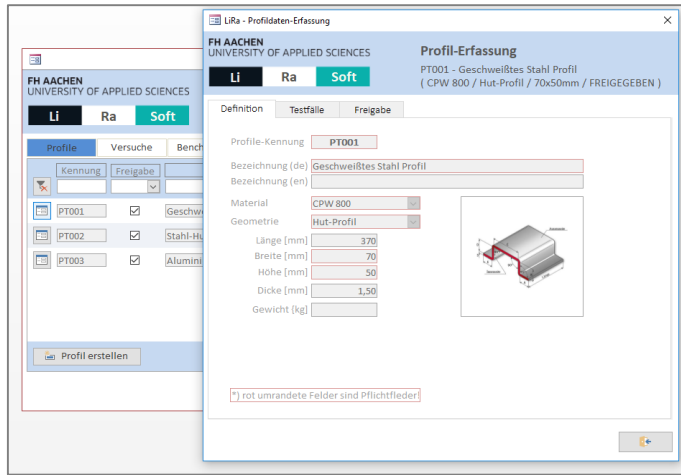
Technology Selection

Analysis & Result

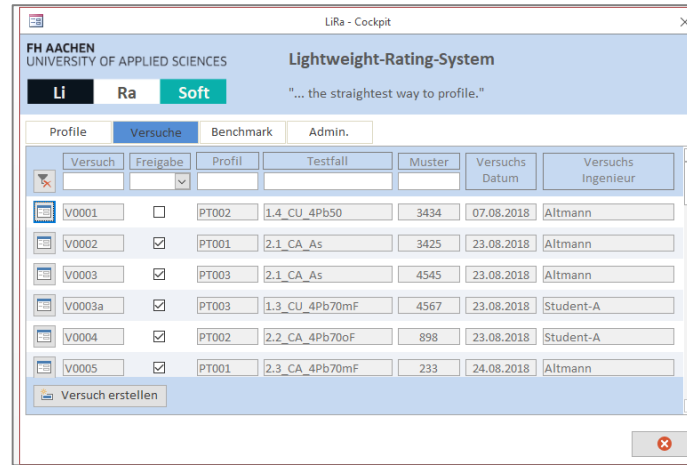


Proposal  
Technology  
for B-Post

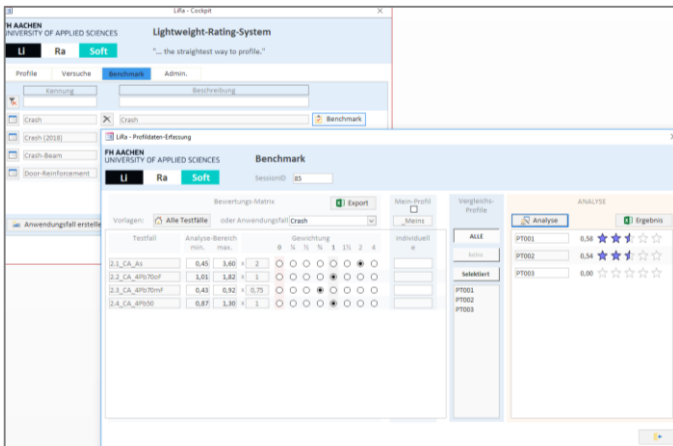
# Having an Insight into the Software of LWR-Soft (Back End)



Geometrical Input-Data of Technology



Input of all Testing and Analysis-Data



Benchmark-Result & Rating & (Proposal of Vehicle Area)



Analysis within Program Code

## Summary

- With “LWR-Soft” a Light Weight Rating System for Body and Chassis-Structures has been introduced for the first time
- LWR-Soft is a Knowledge Based Tool for the Predevelopment of Vehicle Structures and it can be Used to Validate FEM-Models or the development of FEM-Methods
- Future Body Structures now can be rated with respect to an „objective“ State of the Art Standard of Vehicle Structures

## Next Step

- Market Feedback to be gained
- Partner to be looked for to bring LWR-Soft to Industry-Standards

# Thank You for Your Attention!



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