Design Advisor Workshop

Session 3

Mass Estimation Fundamentals

Scaling Component mass

Estimating secondary mass changes

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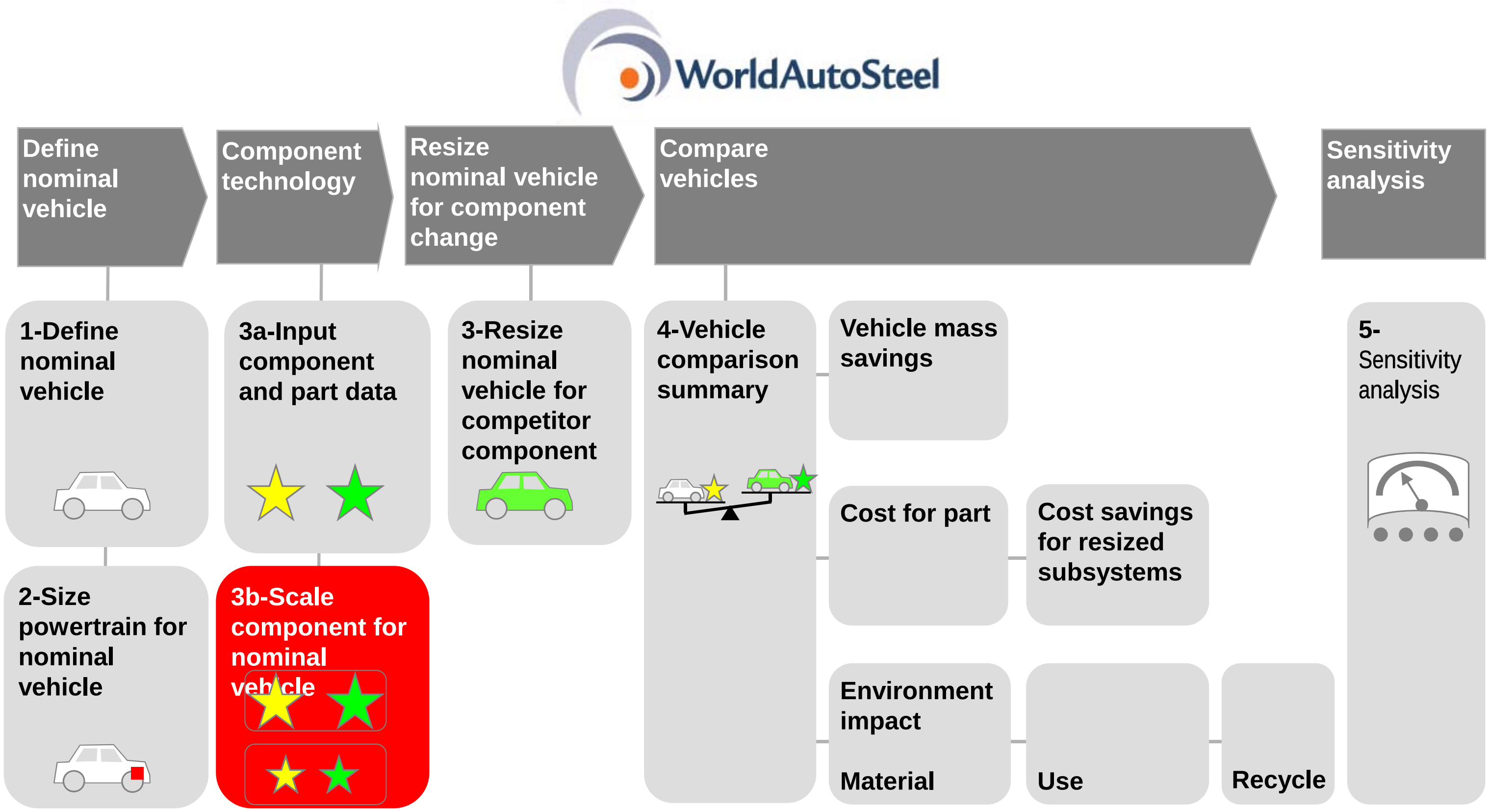
Design Advisor Solution Map



Case Study 2- Hood

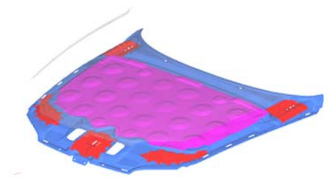
Plans for 20xx vehicle

hood area=1.5 m^2

Component: Hood

Area=2 m^2

AHSS
14.66 kg



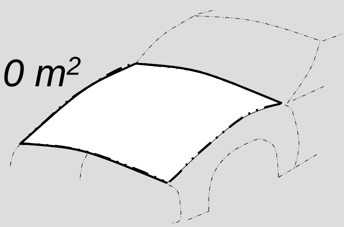
Area=2 m^2

Aluminum
11.00 kg

Scaling Component Mass

We have mass information on a hood from a previous study

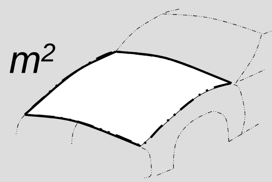
$A=2.0\ m^2$



$m_{HOOD}=14.66\ kg$

The nominal vehicle has different hood size

$A=1.5\ m^2$



$m_{HOOD}=?$

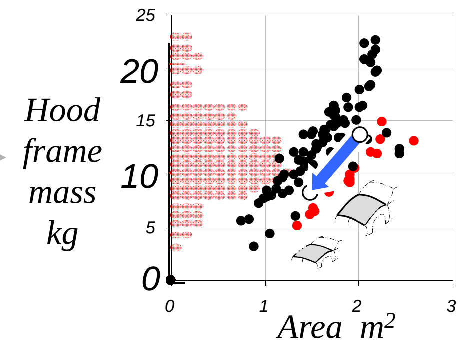
How should we scale this mass data to represent the mass of a hood for the nominal vehicle?

Scaling Component Mass

Mass Drivers determined by statistical significance

$$\hat{m} = 4.28(Area\ \ m^2)^{1.24}\begin{bmatrix}1.65 Conv.Steel\\ 1.00 Aluminum\end{bmatrix}$$

Subsystem Attributes | **Component Interaction** | **system Attributes**



benchmarking-130 hoods

resulting scaling equation $$\frac{\hat{m}_A}{\hat{m}_B} = \left[\frac{Area_A}{Area_B}\right]^{1.24}$$

ε

$$\frac{\hat{m}_A}{14.66} = \left[\frac{1.5}{2}\right]^{1.24} = 10.26$$

Scaling Component Mass

Closures

hood frame

$$\hat{m} = 4.28(Area\ \ m^2)^{1.24}$$

deck lid frame

lift gate frame

hatch frame

door frame

Chassis

knuckle

$$\hat{m} = 0.343(FGAM, kg)^{0.478}\begin{pmatrix}0.571 McPherson \\ 1.00 SLA\end{pmatrix}$$

Lower control arm

wheel

exhaust

Body

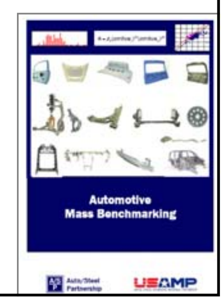
body shell

$$\hat{m} = 3.418(GVM, kg)^{0.438}(Area, m^2)^{0.599}$$

instrument panel beam

front seat frame

bumper beam



The math

Scaling Component Mass

$$\frac{m_A}{m_B} = \left[\frac{MassDriver_A}{MassDriver_B}\right]^{\beta}$$

$$m_A = \left[\frac{MassDriver_A}{MassDriver_B}\right]^{\beta} m_B$$

where

m_A =*mass of component to be determined*

m_B =*mass of reference component*

β =*exponent from mass driver equation*

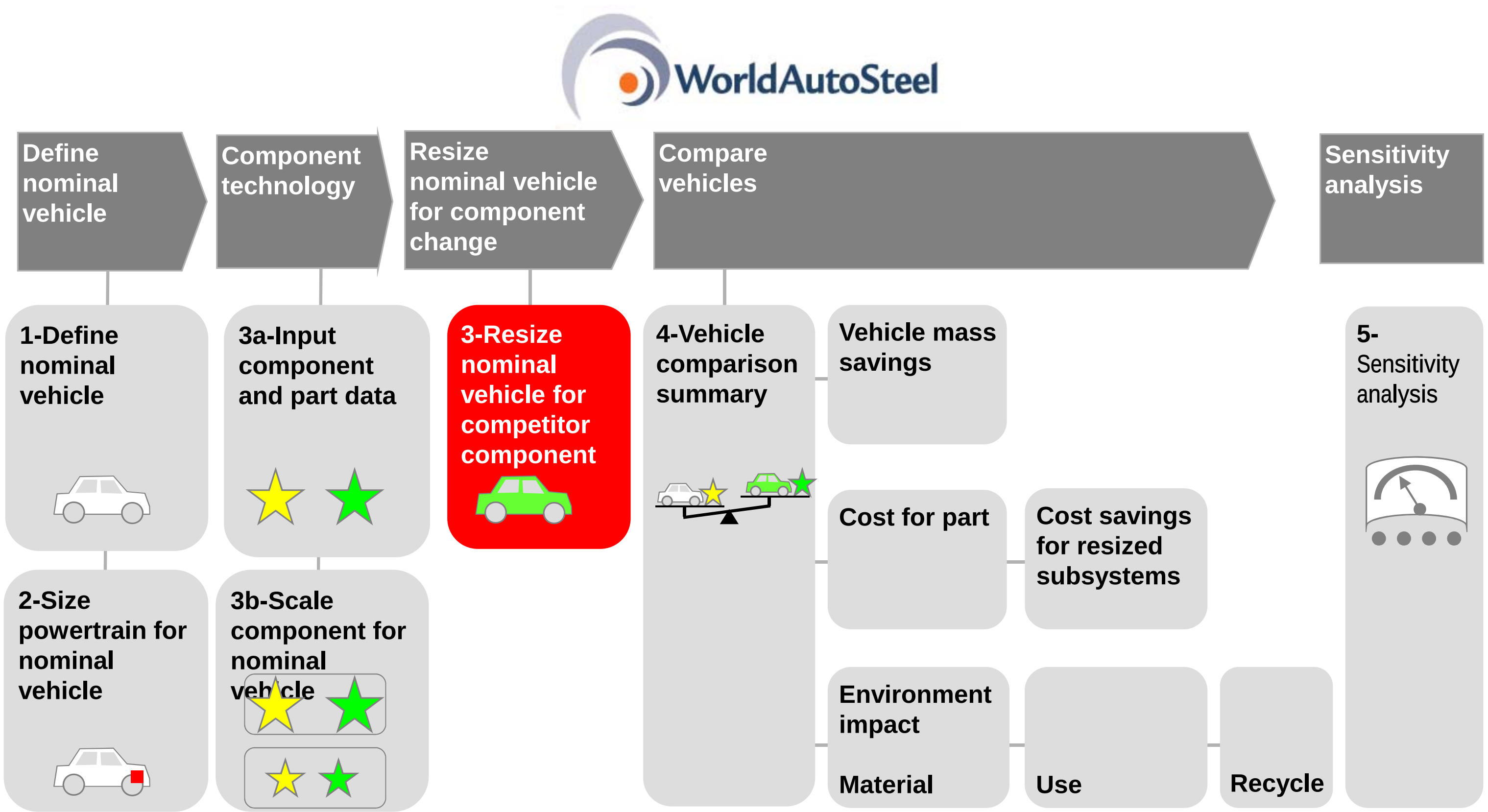
example *mass driver equation for door frame*

$$\hat{m}(kg) = 11.06(Area\ \ m^2)^{0.867} 1.41 Fe$$

resulting scaling equation to account for changing door area

$$\frac{\hat{m}_A}{\hat{m}_B} = \left[\frac{Area_A}{Area_B}\right]^{0.867}$$

Design Advisor Solution Map



Estimating secondary mass changes

Resizing Nominal Vehicle - Mass Compounding

WorldAutoSteel

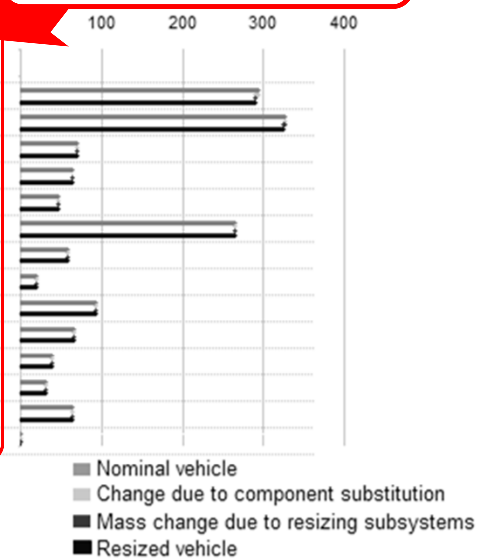
Vehicle type: Sedan/Hatchback

Mass influence coefficient source: Analytical

Resizing method: (•) Simple ( ) Compounded

How is nominal vehicle resized?

Subsystem	Subsystem Mass Influence Coefficient	*Source= User Defined* Enter influence coeff.	resize sub-system ?	Nominal Vehicle Mass	Component mass change	Resized Vehicle Mass
Body Non-structure	0.000			292.89	-4.00	288.89
Body Structure	0.096		☑	325.91	0.00	325.53
Front Suspension	0.025		☑	70.35	0.00	70.25
Rear Suspension	0.025		☑	63.17	0.00	63.07
Braking	0.037		☑	45.94	0.00	45.80
Powertrain	0.081		☑	265.61	0.00	265.29
Fuel & Exhaust	0.010		☑	57.43	0.00	57.39
Steering	0.007		☑	20.10	0.00	20.07
Tires & Wheels	0.022		☑	93.32	0.00	93.24
Electrical	0.000			66.04	0.00	66.04
Cooling	0.000		☑	38.77	0.00	38.77
Bumpers	0.000		☑	31.59	0.00	31.59
Closures	0.000			64.61	0.00	64.61
Battery (electric car)	0.000		☑	0.00	0.00	0.00
Sum Inf. Coeff (sum must be <1)	0.303	*Curb Mass (kg)*		1435.75		1430.54
		Passenger Mass (kg)		340.19		340.19
		Cargo Mass (kg)		100.00		100.00
		Gross Vehicle Mass (kg)		1875.94		1870.73
		Change from Nominal (kg)			-4.00	-5.21
		Curb+two passengers (Lb)		3465.28		3453.80



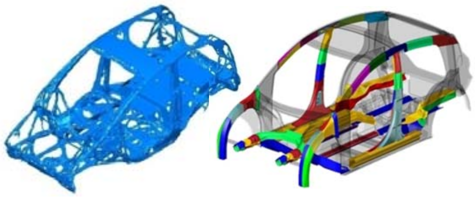
Primary Mass Change

Represented as the mass difference between
Original component and Competing Component in the Design Advisor

Competing Component designed to same requirements as original component, but something has enabled lightweighting

Innovative materials

AHSS (Advanced High Strength Steels)

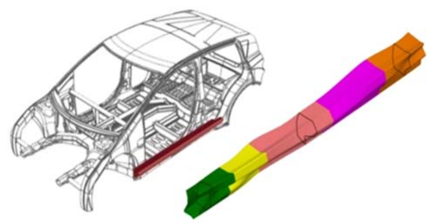


CFRP
(Carbon fiber reinforced materials)

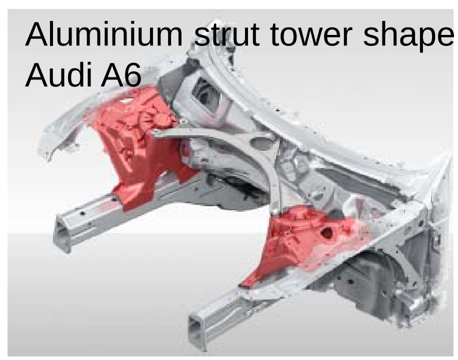
Aluminum

Design optimization

Future Steel Vehicle rocker

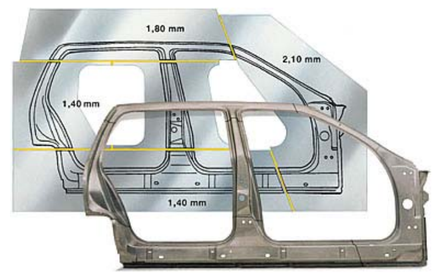


Aluminium strut tower shape
Audi A6



Production methods

Tailored blanks



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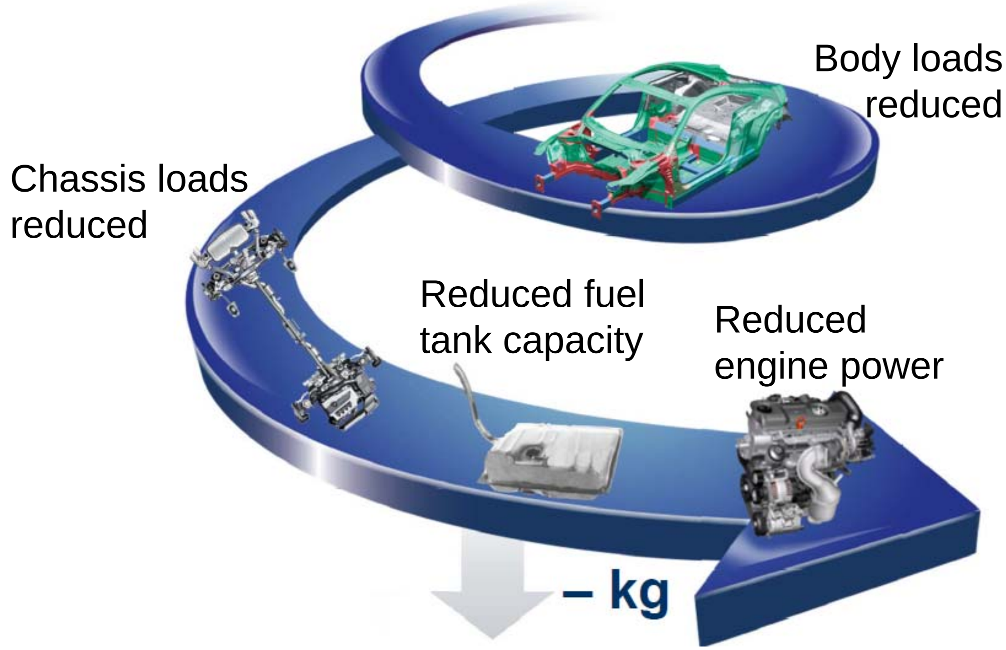
Primary and Secondary Mass Change

Primary mass change due to component substitution



Secondary mass change due to resizing subsystems

No lightweighting enablers needed. This mass reduction is due to reduced requirements on subsystems

Source:
Aachener Karosserietage 2012 (VW AG)

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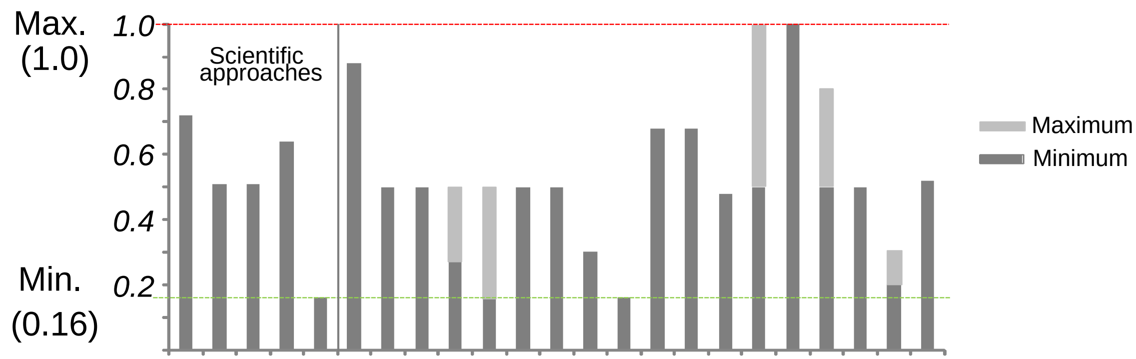
Secondary Mass

Quantifying secondary mass changes

$$M_{RS} = M_0 + \Delta + \Delta\Gamma$$

- M_{RS}: Vehicle mass after resizing subsystems
- M_0: Initial vehicle mass for which the subsystems are sized
- Δ: *primary* mass change, + increase, - reduction
- $\Delta\Gamma$: *secondary* mass change due to resizing subsystems

Γ secondary mass per primary mass change kg/kg



Literature source
(see paper for references)

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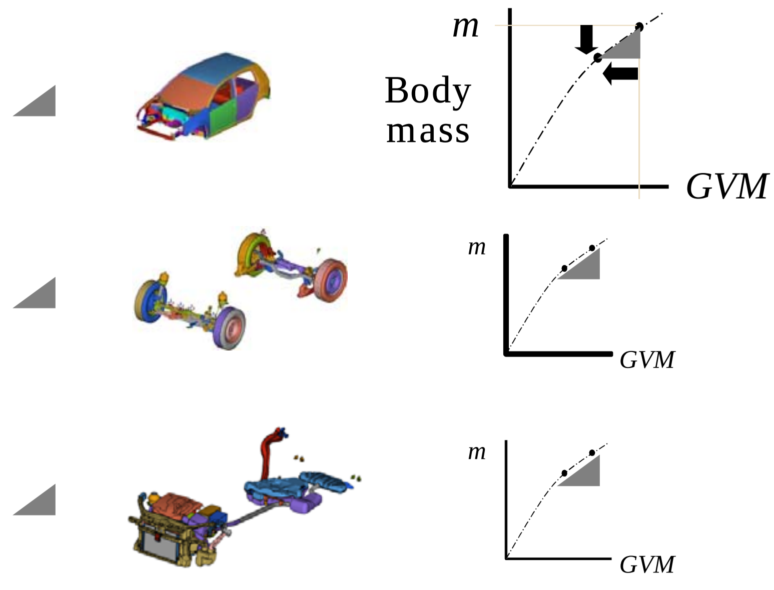
Secondary Mass Influence Coefficients

Subsystem influence coefficients

Vehicle Secondary mass coefficient, Γ

Subsystem mass influence coefficient **-** Change in mass of a subsystem due to a unit mass change in the Gross Vehicle Mass (kg/kg).

Γ *depends on* $\gamma_V = SUM$



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Simple and Compounded Secondary Mass Change

Example values only

	influence coefficient	subsystem mass reduction		
Resizing iteration		**1**	**2**	**∞**
Begin with Primary reduction $\Delta =$		**100**	-35.00	
Body Structure	0.10	-10.00	-3.50	
Suspension	0.05	-5.00	-1.80	
Braking System	0.04	-4.00	-1.40	
Powertrain	0.10	-10.00	-3.50	
Fuel Tank System	0.01	-1.00	-0.40	
Steering System	0.01	-1.00	-0.40	
Tires and Rims	0.04	-4.00	-1.80	
Secondary mass savings for iteration		-35.00	+ -12.80	
			=	
Cumulative secondary mass savings		-35.00	-47.80	-53.90

Simple Secondary Mass Change
$\Delta\gamma_V$

Compounded Secondary Mass Change
$\Delta\gamma_V / (1-\gamma_V)$

Note: Secondary mass coefficient is not applied to each subsystem. Therefore material composition of vehicle will change slightly.

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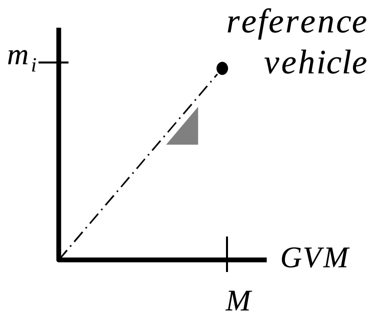
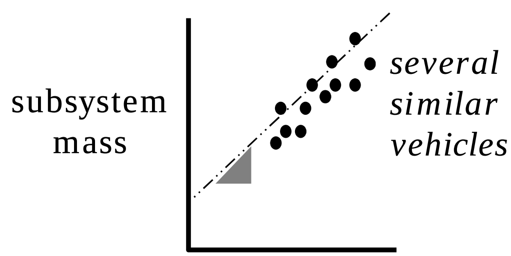
Secondary Mass estimation Methods

Ratio method



$$\gamma_i = m / M$$

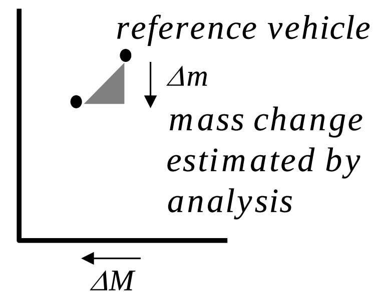
Regression method

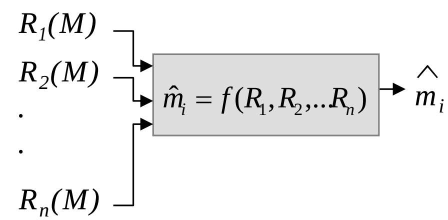


$$\hat{m} = \beta_0 + \beta_1(GVM) + \beta_2(mass.driver_2) + \varepsilon$$

$$\gamma_i = \frac{\partial \hat{m}}{\partial GVM}$$

Analytic method





R: requirements ***which depend on GVM***

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Regression Method

Fit statistical model of subsystem mass data using a set of vehicles

$$\hat{m}_{SUBSYSTEM} = \beta_0 + \beta_1(GVM) + \beta_2(mass.driver) + \varepsilon$$

69 sedan and hatchback vehicles (model years 2000 to 2008)

Size range:	*A class to D class (curb mass 920 kg to 1600 kg)*
Subsystem technology:	*Integral steel body*
	Transverse front wheel drive
	Internal combustion engine
	McPherson strut front suspension

Database – a2mac1.com

Ideal assumptions	Violations
Meet same performance requirements	Not same but within competitive range
Subsystems for each vehicle are sized to the particular GVM of that vehicle	Platform sharing: sized to heaviest member Sized to heaviest powertrain, not one in car

Assumption violations will be quantified with error bands

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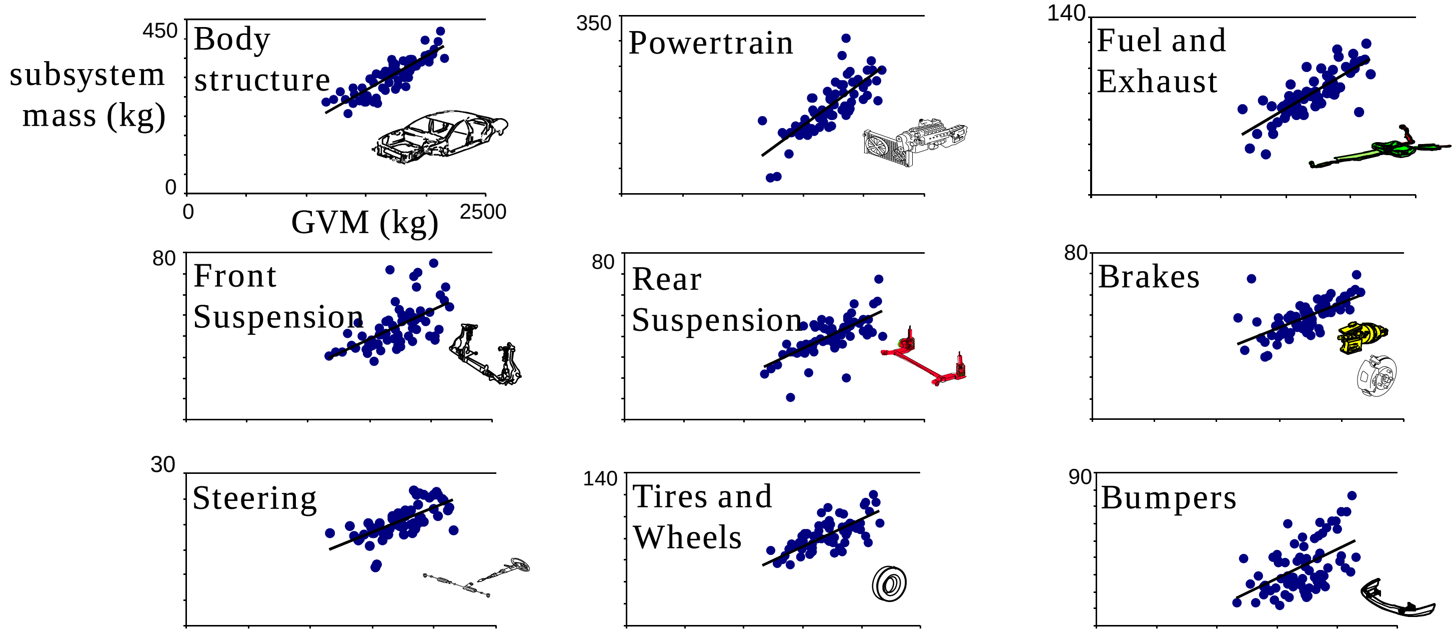
Regression Method

Relationships between the subsystem mass and gross vehicle mass (GVM)



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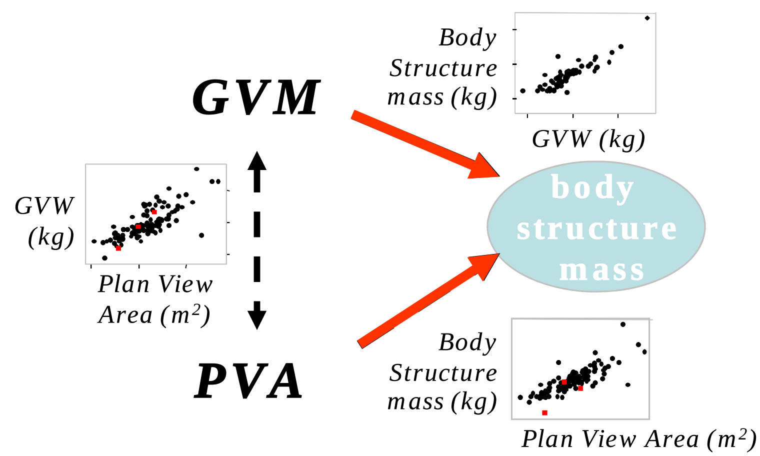
Regression Method

The need to consider all mass drivers



Incorrect statistical model	Better statistical model
$\hat{m}_{BODY.STRUCTURE} = \beta_0' + \beta_1'(GVM) + \varepsilon'$	$\hat{m}_{BODY.STRUCTURE} = \beta_0 + \beta_1(GVM) + \beta_2(PlanViewArea) + \varepsilon$
$\beta_1'=0.173$ reflects the dependence of body structure mass on GVM, but also the confounded dependence on area.	$\beta_1=0.127$ lower because the variability of body mass with area is now being included in coefficient β_2.

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Regression Method

Results for influence coefficients by Regression method

Subsystem	Mass drivers determined by statistical significance	Regression based mass influence coefficient
Body Structure	• Gross vehicle mass • Plan view area *(length x Overall)*	*0.127 ±0.033*
Powertrain	• Gross vehicle mass • Acceleration time *(0-100 km/h time)*	*0.117 ±0.034*
Front Suspension	• Gross front axle mass *(~0.6 x GVM)*	*Front and rear 0.055 ±0.012*
Rear Suspension	• Gross rear axle mass *(~0.4 x GVM)*	
Steering System	• Gross front axle mass *(~0.6 x GVM)*	*0.009 ±0.003*
Braking System	• Gross vehicle mass	*0.024 ±0.007*
Tires & Rims	• Gross vehicle mass	*0.050 ±0.012*
Fuel Tank System	• Gross vehicle mass • Engine displacement	*0.026* *(fuel tank only)*

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Analytical Method

Determination of the secondary mass change

Analytic approaches:

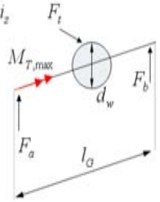
- •Clutch
- •Gearbox
- •Differential
- •Drive shafts / Cardan shaft
- •Brakes
- •Tires and Rims
- •Fuel consumption

$$F_t = \frac{2 \cdot M}{d_w} \quad M_{B,\max} = \frac{F_t \cdot l}{4} \quad M_{T,\max} = M_{mot} \cdot i_z$$

$$M_V = \sqrt{(M_{B,\max})^2 + 0,75 \cdot (\alpha_0 M_{T,\max})^2}$$

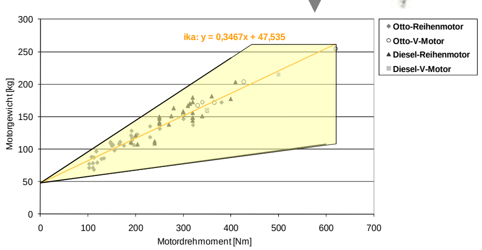
$$d_{\min} = 2,17 \cdot \sqrt[3]{\frac{M_V}{\sigma_{B,zul}}} \quad \sigma_{B,zul} = \frac{\sigma_{b,W}}{S_D}$$

α_0 = Anstrengungsverhältnis
M_V = Vergleichmoment



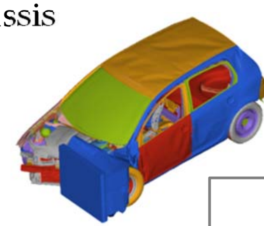
Empirical approaches:

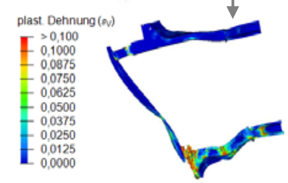
- •Engine
- •Clutch pressure disc
- •Cooling system
- •12 volt battery
- •Fuel tank housing
- •Vertical dynamics
- •Steering system



Simulations:

- •Body
- •Chassis





Bauteil	Gewicht Referenz [kg]	Gewicht reduziert [kg]	Gewichtsein-sparung [kg]	Gewichtsein-sparung [%]
Querträger (v)	4,15	2,65	1,50	36,1%
Crashbox (l, u)	0,33	0,19	0,14	42,4%
Crashbox (l, o)	0,28	0,15	0,13	46,4%
Crashbox (r, u)	0,33	0,19	0,14	42,4%
Crashbox (r, o)	0,28	0,15	0,13	46,4%
Längstr. (v, l, T1)	0,72	0,41	0,31	43,1%
Längstr. (v, r, T1)	4,53	2,44	2,09	46,1%
Längstr. (v, l, T2)	0,74	0,43	0,31	41,9%
Längstr. (v, r, T2)	4,59	2,47	2,12	46,2%
Längstr. (v, l, o)	2,06	1,93	0,13	6,3%
Längstr. (v, r, o)	1,96	1,81	0,15	7,7%
Gesamt	19,97	12,82	7,15	35,8%

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Analytical Method

Analytic Method Results

Results of the secondary mass change calculation (e.g. VW Golf V)

Vehicle data:	
Model	VW Golf V
Engine	2.0 l - Diesel engine (turbocharged)
Curb weight	1405 kg
GVM	1910 kg
Wheel base	2578 mm
Tires	195/60 R 15
Fuel capacity	55 l
Gearbox	6 gear manuel gearbox
Engine power	140 PS (103 KW) at 4000 U/min
Front axle	McPherson
Rear axle	Control blade suspension

Primary mass change

100 kg

Functional group	SMC
Body structure	9.6 kg
Suspension	5.0 kg
Braking system	3.7 kg
Powertrain	10.6 kg
Fuel tank system	1.0 kg
Steering system	0.7 kg
Tires and Rims	3.6 kg
Simple SMC	34.2 kg
Compounded SMC	51.9 kg

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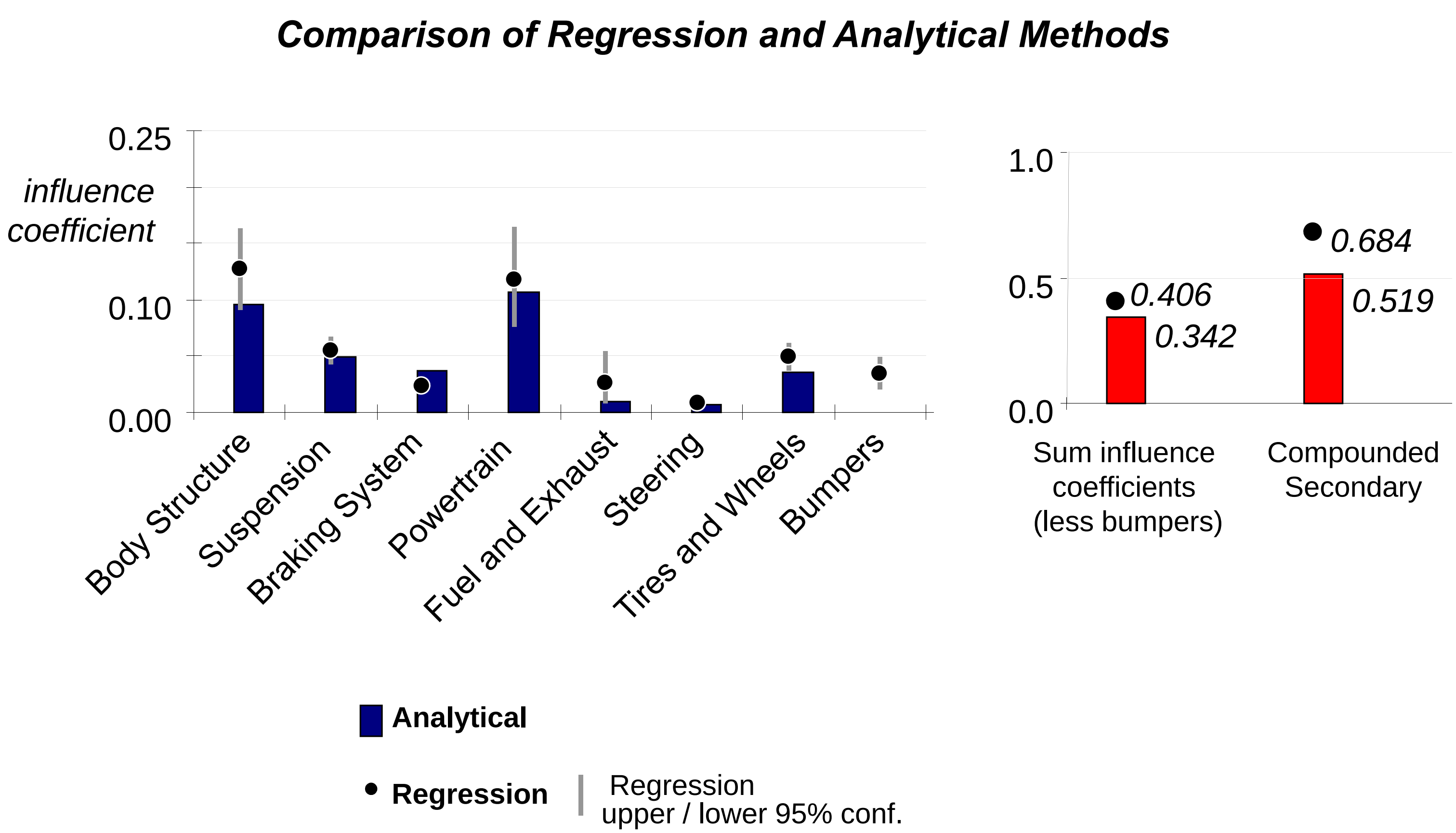
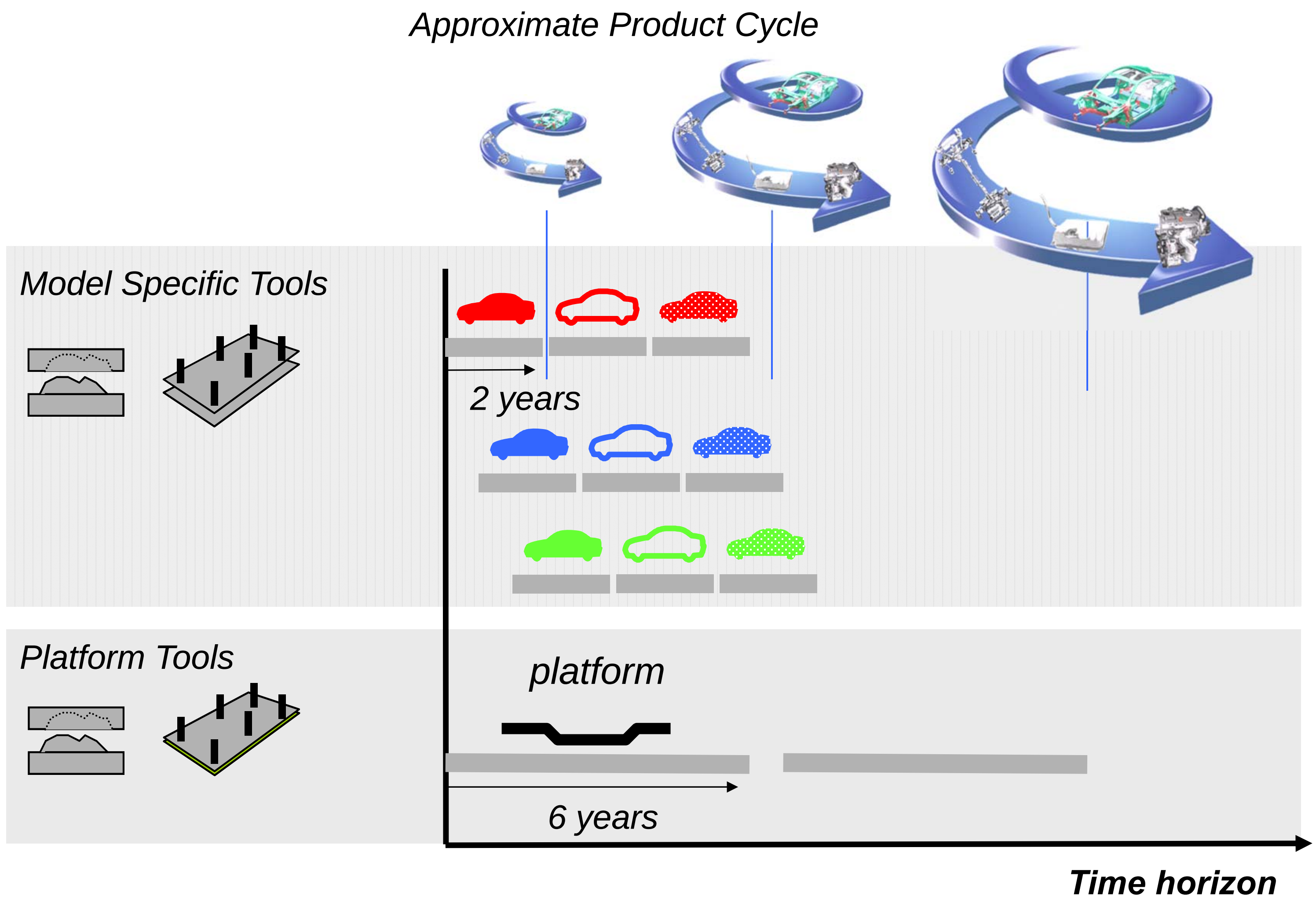
Secondary Mass Change



Which Type of Secondary Mass?



Which Type of Secondary Mass?

Time horizon for Design	*1-2 years into future*	*3-6 years into future*	*12 years into future*
	Mid cycle enhancement of an existing product	*New vehicle program/New architecture*	*Strategic Planning more than two architecture cycles into future*
	Tactical resizing of some subsystems which are to be enhanced. Other design changes limited to small changes due to tooling	*New Architecture using OEM's existing BOM*	*Opportunity to change OEM's BOM*
Secondary mass type	***Simple*** *subsystems limited*	***Simple*** *subsystems as defined in program plan*	***Compounded*** *all subsystems resized*

The math

Mass compounding

for vehicle $$M_{RS} = M_0 + \Delta + \Delta\Gamma$$

where,

M_0 =Initial vehicle mass for which the subsystems are sized

Δ =Initial total mass change (primary mass change)

M_{RS} =Resized vehicle mass

$\Delta \cdot \Gamma$ =Additional (secondary) mass change due to resizing all subsystems

$$\Gamma = \gamma_V$$ for simple secondary mass

$$\Gamma = \frac{\gamma_V}{1-\gamma_V}$$ for compounded secondary mass

γ_V =Mass influence coefficient for the vehicle given by

$$\gamma_V = \Sigma \gamma_i$$

γ_i =Mass influence coefficient for subsystem *i*

The math

Mass compounding

for subsystem i $mi_{RS} = mi_0 + \Delta_i + \Delta\tau$

$\tau = \gamma i$ for simple secondary mass

$\tau = \dfrac{\gamma i}{1-\gamma_V}$ for compounded secondary mass

where,

mi_0 = Initial subsystem i mass

Δ_i =Initial mass change in subsystem i

Δ =Initial total mass change (primary mass change)

mi_{RS} =Resized subsystem i mass

$\Delta_i \cdot \tau$ =Additional (secondary) mass change for subsystem i

How material content changes are not so obvious

Remove *Δ=-100 kg* from subsystem 3

System	τ_i	m_i		BOM $\phi_{Row,Col}$		
subsys	inf coeff	base mass	With simple secondary mass change	mat A	mat B	mat C
1	*0.05*	*500*	*495*	*0.9*	*0.1*	*0*
2	*0.15*	*300*	*285*	*0.2*	*0.8*	*0*
3	*0.00*	*200*	*100*	*0*	*0*	*1.0*
	0.20					
Mass kg		*1000*	*880*			

Mat A kg	*510*	*502.5*
Mat B kg	*290*	*277.5*
Mat C kg	*200*	*100.0*

$$\mathcal{M}_A = \left(m_1\phi_{1A} + m_2\phi_{2A} + m_3\phi_{3A}\right)$$
$$\mathcal{M}_B = \left(m_1\phi_{1B} + m_2\phi_{2B} + m_3\phi_{3B}\right)$$

Mat A change kg	*-7.5*
Mat B change kg	*-12.5*

$$\partial\mathcal{M}_A = \Delta\left(\tau_1\phi_{1A} + \tau_2\phi_{2A} + \tau_3\phi_{3A}\right)$$
$$\partial\mathcal{M}_B = \Delta\left(\tau_1\phi_{1B} + \tau_2\phi_{2B} + \tau_3\phi_{3B}\right)$$

% of secondary mass change composed of		
	Material A	37.50%
	Material B	62.50%

Excel sheet

Material composition of Secondary mass change change inf coeff, material BOM

Primary change -100 all from subsystem 3

subsys	inf coeff	mass original	mass simple	mass comp	BOM mat A	mat B	mat C
1	*0.05*	*500*	*495*	*493.75*	*0.9*	*0.1*	*0*
2	*0.15*	*300*	*285*	*281.25*	*0.2*	*0.8*	*0*
3	*0*	*200*	*100*	*100*	*0*	*0*	*1*
	0.2						
	Mass kg	*1000*	*880*	*875*			
secondary	mass change		*20*	*25*			
	Mat A kg	*510*	*502.50*	*500.63*			
	Mat B kg	*290*	*277.50*	*274.38*			
	Mat C kg	*200*	*100.00*	*100.00*			

Mat A change kg	*-7.50*	*-9.38*
Mat B change kg	*-12.50*	*-15.63*

% of secondary mass change composed of

Material A	***37.50%***	***37.50%***
Material B	***62.50%***	***62.50%***

$$\%\ Secondary\ mass\ change\ composed\ of\ material\ A = \frac{(\tau_1\phi_{1A} + \tau_2\phi_{2A} + \tau_3\phi_{3A})}{(\tau_1 + \tau_2 + \tau_3)}$$

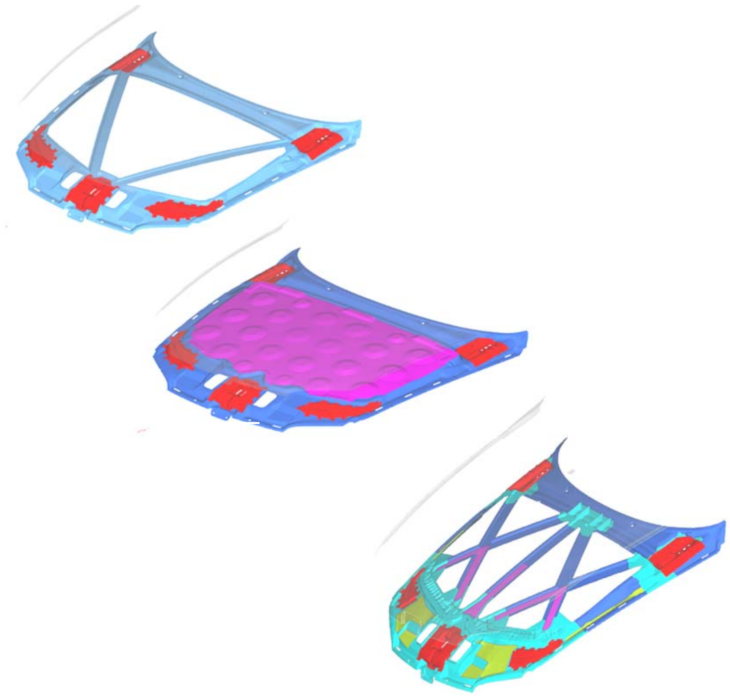
Case Study 2- Hood Data

Lightweight Vehicle Consortium
J. Dahmus and R. Roth, September 11, 2008

Results Summary – Hood

	Primary Process	Total Mass (kg)
Steel II	Stamping	14.66
Aluminum	Stamping	11.00
Sheet Molding Composite	SM Press	18.00

All hoods have surface area=2 m²



Case Study 2- Hood

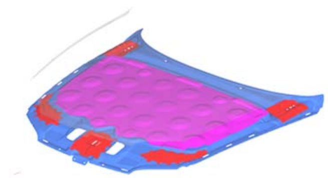
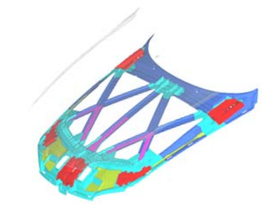
Plans for 20xx vehicle

hood area=1.5 m^2

Vehicle type: Hatchback
L=4.2 m
W=1.750 m
100 kg cargo

New architecture
Internal Combustion-Gasoline
Powertrain is fixed and will not change
6. liter/100 km (HYZEM schedule)
Life time range =*155,000 km*

Component: Hood

		
Area=2 m^2	*Area=2 m^2*	*Area=2 m^2*
Original Component	**Competitor 1 Component**	**Competitor 2 Component**
AHSS	Aluminum	SMC
Stamped	Stamped	SM Press
14.66 kg	11.00 kg	18.00 kg

Case Study 2 – Hood

Purpose: To see how the secondary mass method affects results

Load input data by starting at the ***Set Nominal Vehicle*** sheet and stepping through sheets using the forward arrow in upper right corner. Begin with AHSS vs Aluminum hood

1. Make sure to enter original and new hood area on ***Input Component Data*** sheet
2. On ***Resize Nominal Vehicle*** Sheet choose *Analytical* , *Simple* *as secondary mass method*
3. On ***Vehicle Comparison Summary*** sheet observe mass, cost, and GHG results
   Record data in the table below
4. Use the circle icon in the upper right corner to go to ***Solution Map***.
   Choose ***Resize Nominal Vehicle*** icon
5. Change secondary mass method as shown in the table below
6. Use forward arrow in the upper right corner to go to ***Vehicle Comparison Summary***
7. Observe Mass, Cost, and GHG results
   Record data in the table below
9. If time permits, repeat for AHSS vs. SMC hood

Secondary Mass Method	Primary Mass change	Subsystem Mass change	Secondary cost change	GHG change
Analytical, *Simple*				
Analytical, *Compounded*				
Regression, Simple				
Regression, Compounded				

Case Study 2 – Hood

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9. If time permits, repeat for AHSS vs. SMC hood

All subsystems resized

Secondary Mass Method	Primary Mass change	Subsystem Mass change	Secondary cost change	GHG change
Analytical, *Simple*	*2.56 (-2.34 smc)*	*0.77 (-0.71 smc)*	*0.935 (-0.85smc)*	*6.95 (-200.21smc)*
Analytical, *Compounded*	*2.56 (-2.34 smc)*	*1.11 (-1.01 smc)*	*1.34 (-1.22 smc)*	*4.40 (-200.34 smc)*
Regression, Simple	*2.56 (-2.34 smc)*	*1.16 (-1.06 smc)*	*1.56 (-1.42 smc)*	*3.76 (-203.12 smc)*
Regression, Compounded	*2.56 (-2.34 smc)*	*2.11 (-1.93 smc)*	*2.84 (-2.60 smc)*	*3.72 (-209.95 smc)*