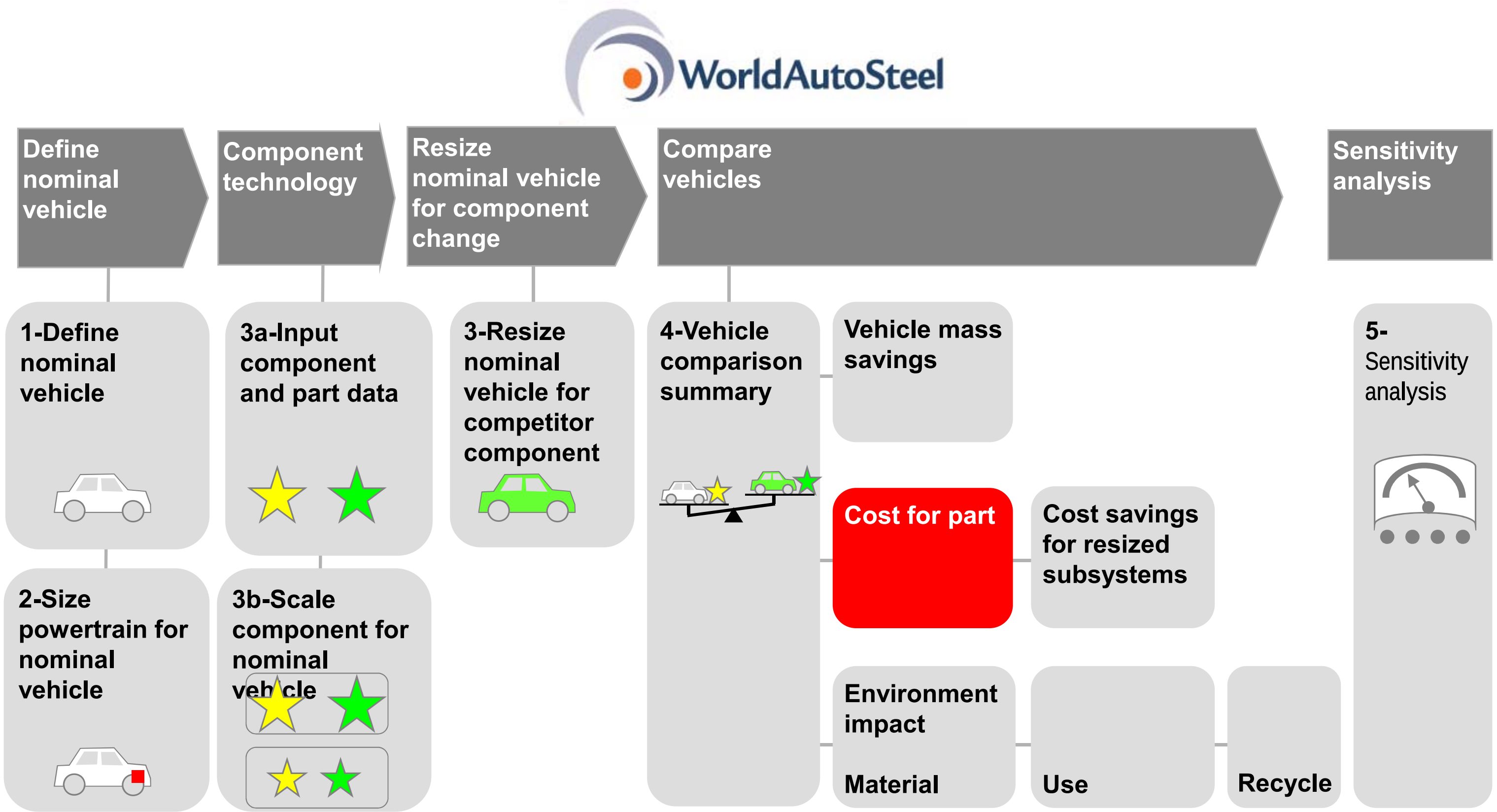
Design Advisor Workshop

Session 4

Cost Estimation

Design Advisor Solution Map



Design Advisor-Component Shaping Cost

Results - Component Shaping Cost Comparison

WorldAutoSteel ?

Part mass (kg)	10.00	6.00	
Material	Steel-Conventional	Magnesium Cast	
Material cost ($/kg)	0.70	5.00	
Component shaping process	Steel Stamping	NonFerrous Die Casting	
Select batch size, n	100,000		
cost per part	**$23.65**	**$37.33**	**$13.68**
material	$8.78		$26.48
tooling	$12.77		-$12.11
equipment	$2.10		-$0.68

How is part shaping cost estimated?

$C=[(m*C_m)/(1-f)]+[C_t/n]+1/n' \; [C_e/(L*two)]+1/n'(C_{oh})$

C= part cost ($)

m=part mass (kg)

Cm= material cost per unit mass ($/kg)

f=scrap fraction

Ct=shaping tool cost ($)

n=batch size (life time)

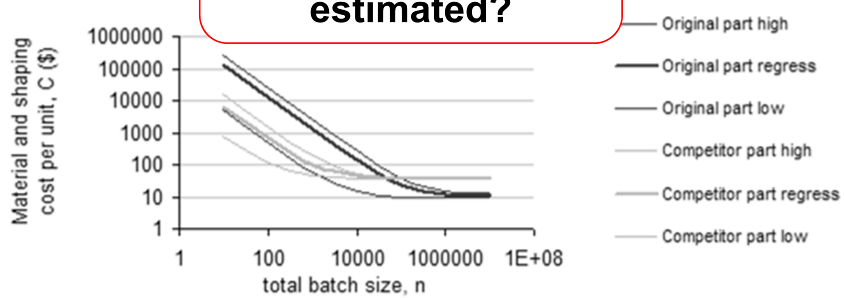
n'=rate of production for process (units/hr)

Ce=cost of equipment

L=equipment utilization fraction (100%)

two=productive life of equipment (yrs) (10yr)

Coh=overhead ($/hour) = 0 for this estimate



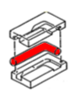
First Order Cost Modeling

Note: Design Advisor cost is limited to Material and Part Shaping cost

$$C = \begin{matrix}\textbf{material}\\ \textbf{cost}\end{matrix} + \begin{matrix}\textbf{tooling}\\ \textbf{cost}\end{matrix} + \begin{matrix}\textbf{equipment}\\ \textbf{cost}\end{matrix} + \begin{matrix}\textbf{overhead}\\ \textbf{cost}\end{matrix}$$

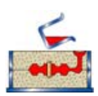
Steel Stamping
Steel Tailor Welded Blank Stamping
Steel Hot Stamping

Steel Open Roll Form



Steel Tubular Hydroforming

Steel Forging



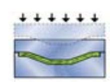
Iron Casting

NonFerrous Stamping

NonFerrous Forging

NonFerrous Extrusion

NonFerrous Die Casting



Composite Sheet Molding Compound

Composite Resin Transfer

CES Process Selection Software, 2011

Shaping cost estimation

$$C = \left[\frac{m\,C_M}{1-f}\right] + \left[\frac{(C_T)}{n}\right] + \frac{1}{\dot{n}}\left(\frac{C_C}{L\cdot t_{WO}}\right) + \frac{1}{\dot{n}}\dot{C}_{OH}$$

material cost | **tooling cost** | **equipment cost** | **overhead cost**

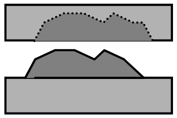
C =Cost per part ($)
C_M =Cost of material ($/kg)
f =Scrap fraction for process and material *note: (yield=1-f)*
C_C =Cost of equipment ($)
C_T =Cost of tooling ($)
$\acute{n}$ =Production rate (number of units made per year)
n =Batch size (number of parts made over life of design)
m =Part mass (kg)
t_{WO} =Capital write-off time (years equipment will be productive)
L =Load factor (fraction of time equipment is productive)
C_{OH} =Overhead rate ($/yr)
(all other costs of production not allocated directly to part)
$C_{OH}=0$ for this analysis

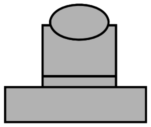
Economic Analysis of Part Shaping

Each cost area is related to part mass

Material — **Specific Tools** — **Reusable Machinery**

$$C = \left[\frac{m\,C_M}{1-f}\right] + \left[\frac{(C_T)}{n}\right] + \frac{1}{\dot{n}}\left(\frac{C_C}{L \cdot t_{WO}}\right)$$





C_M is related to part mass

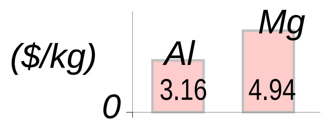
C_T can be related to part mass
heavier parts have greater volume to shape

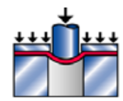
C_C can be related to part mass
heavier parts require greater loads to shape

First Order Cost Modeling

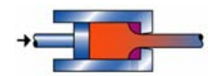
All costs depend on part mass

Material Cost



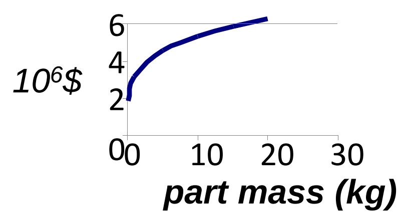


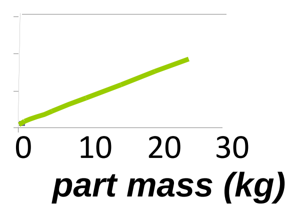
NonFerrous Stamping



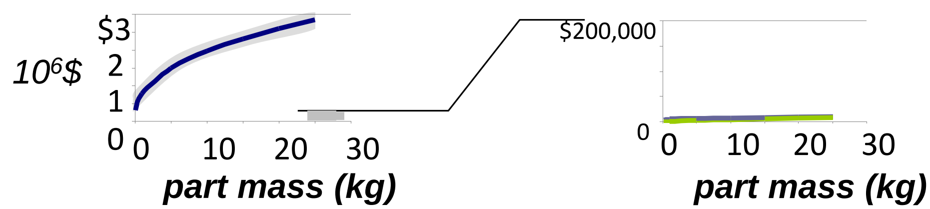
NonFerrous Extrusion

Equipment Cost

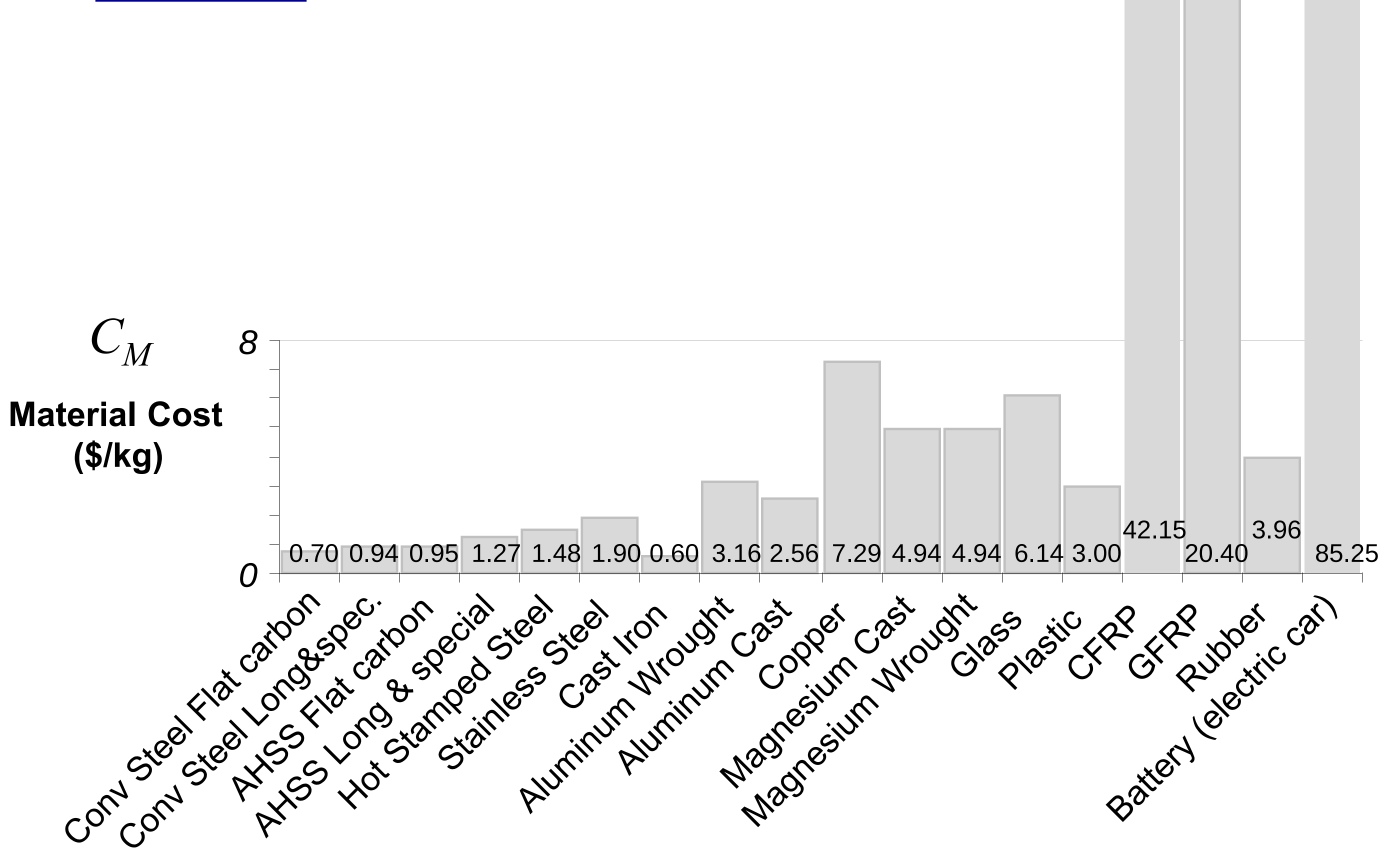




Tooling Cost

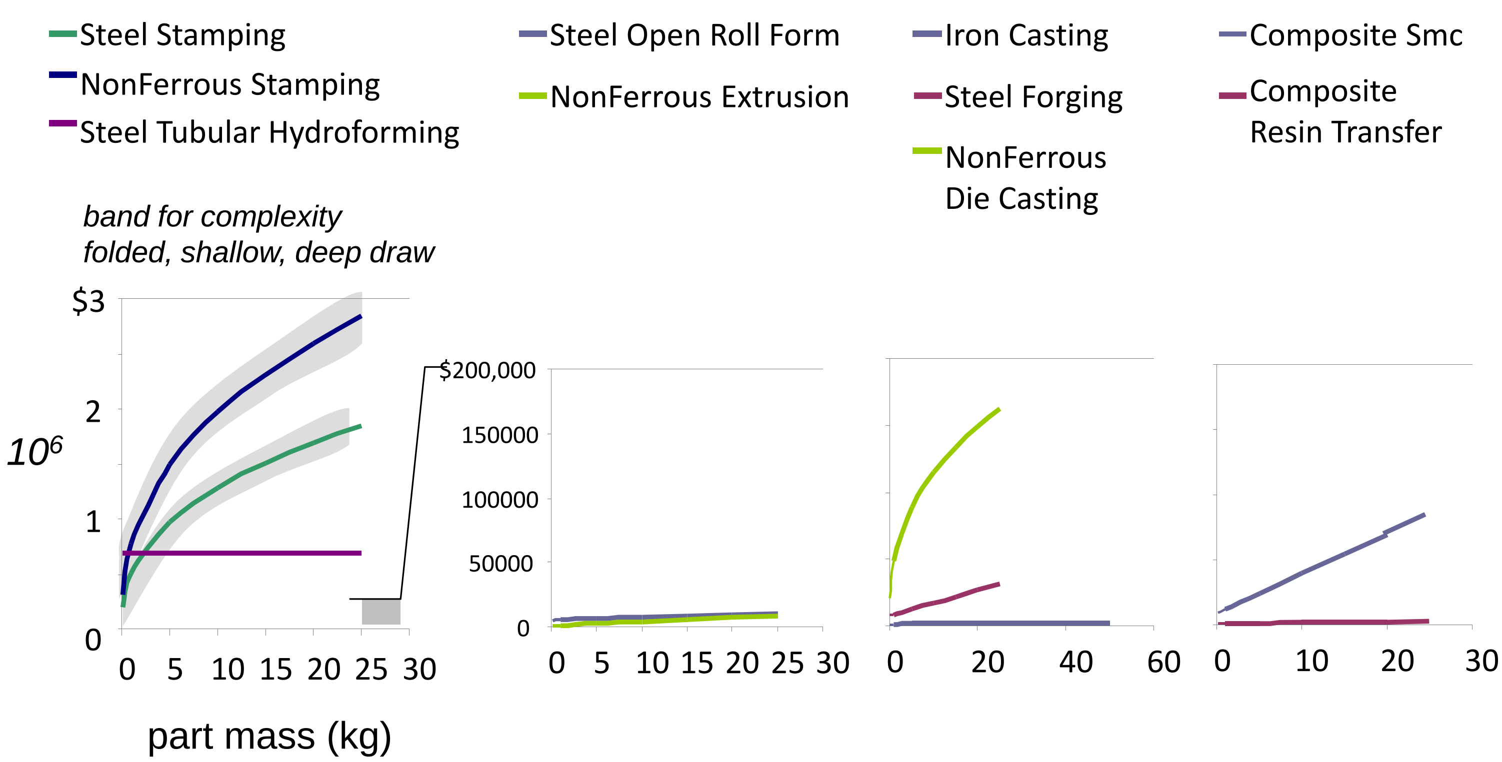


Material Cost per unit mass



Tooling Cost

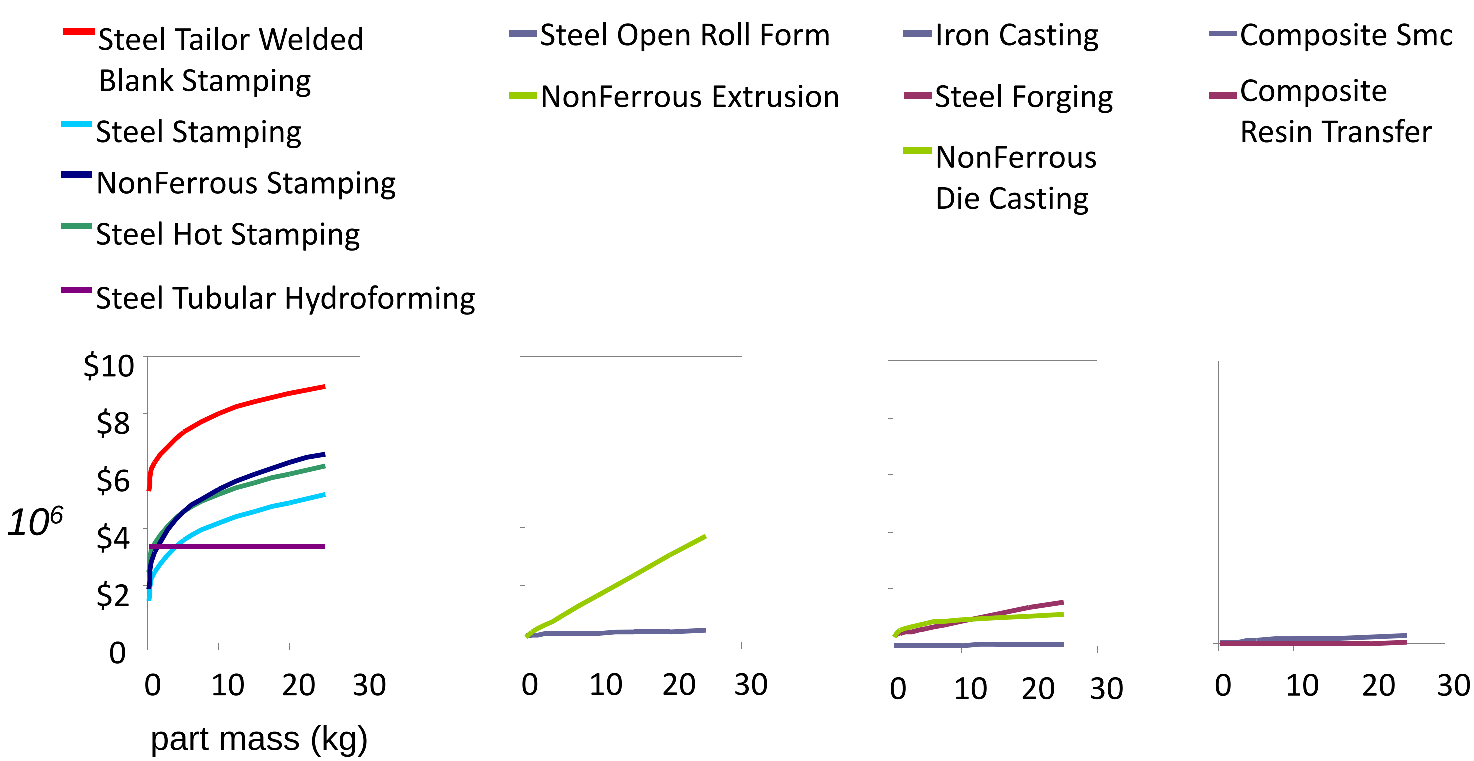
sheet / tube forming metals	prismatic forming metals	bulk forming metals	bulk forming composites



Data from CES material database, MIT, EDAG

Equipment Cost

sheet / tube forming metals | **prismatic forming metals** | **bulk forming metals** | **bulk forming composites**



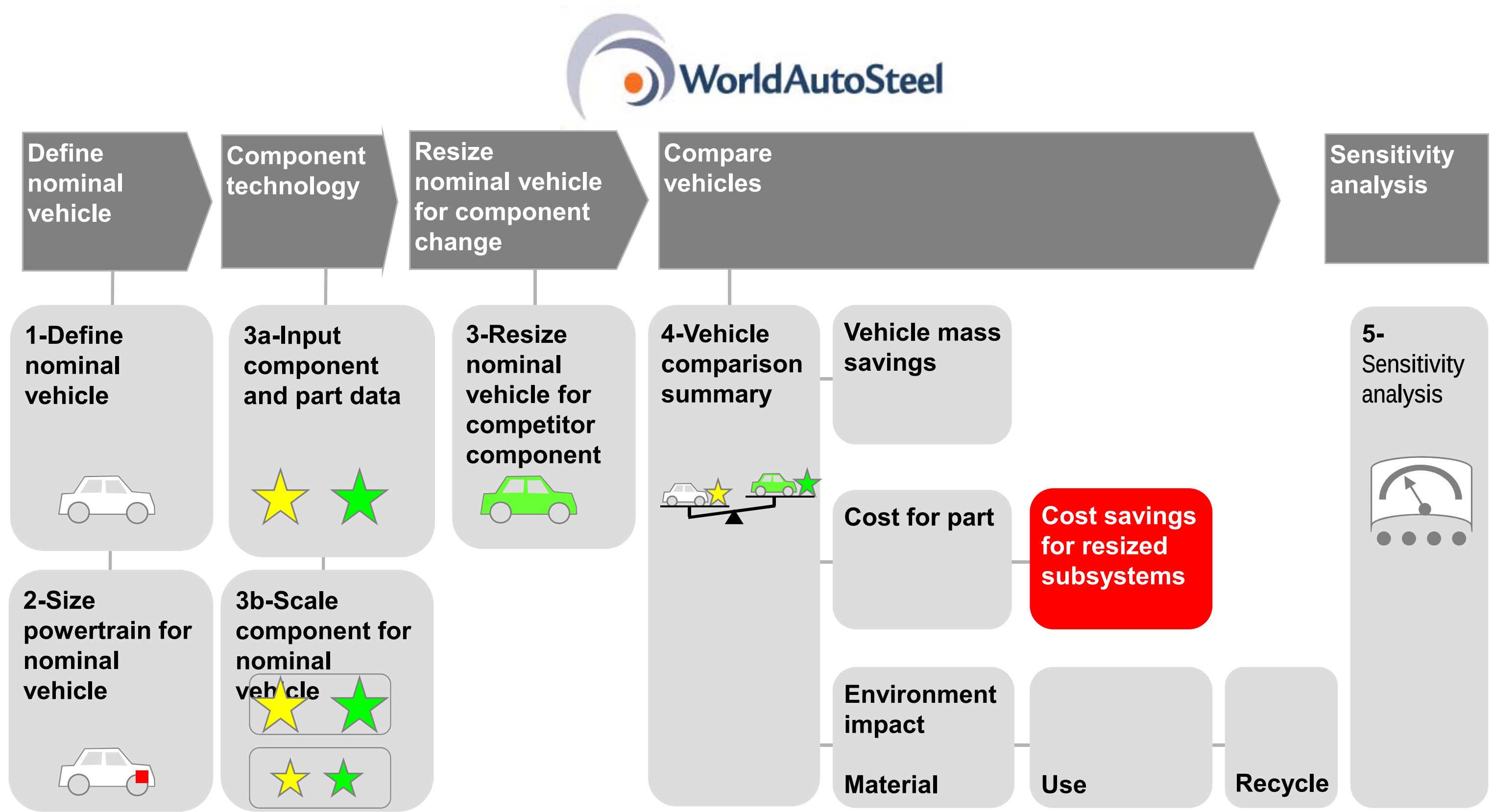
Data from CES material database, MIT, EDAG

The Math

Example for Stamping

Process	$\hat{Y} = \beta_0 (Mass)^{\beta_1} + \beta_2$
Equipment Cost	
Steel Stamping	$\hat{Y} = 2478928(Mass^{0.2282})(0.6494^{Shallow})(1.2202^{DeepDraw})$
Hot Stamping	$\hat{Y} = 2478928(Mass^{0.2282})(0.6494^{Shallow})(1.2202^{DeepDraw}) + 1.0E06$
Tailor Welded Blank Stamping	$\hat{Y} = 2478928(Mass^{0.2282})(0.6494^{Shallow})(1.2202^{DeepDraw}) + 3.8E06$
Non Ferrous Stamping	$\hat{Y} = 3167177(Mass^{0.2282})(0.6494^{Shallow})(1.2202^{DeepDraw})$
Tooling Cost	
Steel Stamping	$\hat{Y} = 506037(Mass^{0.402})(0.5081^{Shallow})(1.2643^{DeepDraw})$
Hot Stamping	$\hat{Y} = 506037(Mass^{0.402})(0.5081^{Shallow})(1.2643^{DeepDraw}) + 1.0E06$
Tailor Welded Blank Stamping	$\hat{Y} = 506037(Mass^{0.402})(0.5081^{Shallow})(1.2643^{DeepDraw}) + 3.8E06$
Non Ferrous Stamping	$\hat{Y} = 779106(Mass^{0.402})(0.5081^{Shallow})(1.2643^{DeepDraw})$

Design Advisor Solution Map



Design Advisor-Resized Subsystem Cost

Results - Cost savings for resized subsystems

WorldAutoSteel

User defined cost coefficients? ☐

Subsystem	Subsystem Cost Coefficient ($/kg)	*User defined* cost coefficient ($/kg)	Consider Resizing Cost?	Nominal Vehicle Mass (kg)	Resized Vehicle Mass (kg)	Cost: Resized relative to nominal ($)
Body Non-structure	2.968			292.89	292.89	0.000
Body Structure	0.703		☑	325.91	325.53	-0.270
Front Suspension	1.219		☑	70.35	70.25	-0.121
Rear Suspension	1.059		☑	63.17	63.07	-0.105
Braking	0.666		☑	45.94	45.80	-0.098
Powertrain	1.258		☑	265.61	265.29	-0.409
Fuel & Exhaust	0.905		☑	57.43	57.39	-0.037
Steering	0.998		☑	20.10	20.07	-0.028
Tires & Wheels	2.449		☑	93.32	93.24	-0.214
Electrical	7.285			66.04	66.04	0.000
Cooling	3.065		☑	38.77	38.77	0.000
Bumpers	1.162		☑	31.59	31.59	0.000
Closures	2.207			64.61	64.61	0.000
Battery (electric car)	85.250		☑	0.00	0.00	0.000
			totals	1435.75	1434.54	**-1.281**

How is cost change due to resizing each subsystem estimated?

Cost change due to subsystem resizing

Original subsystem

m_{NOM}

$\Delta m = m_{RESIZED} - m_{NOM}$

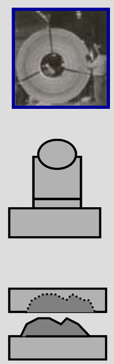
Resized subsystem

$m_{RESIZED}$

Material

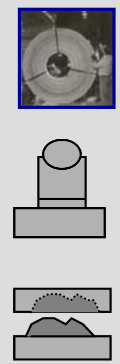
Reusable Machinery

Specific Tools



Consider only material cost difference

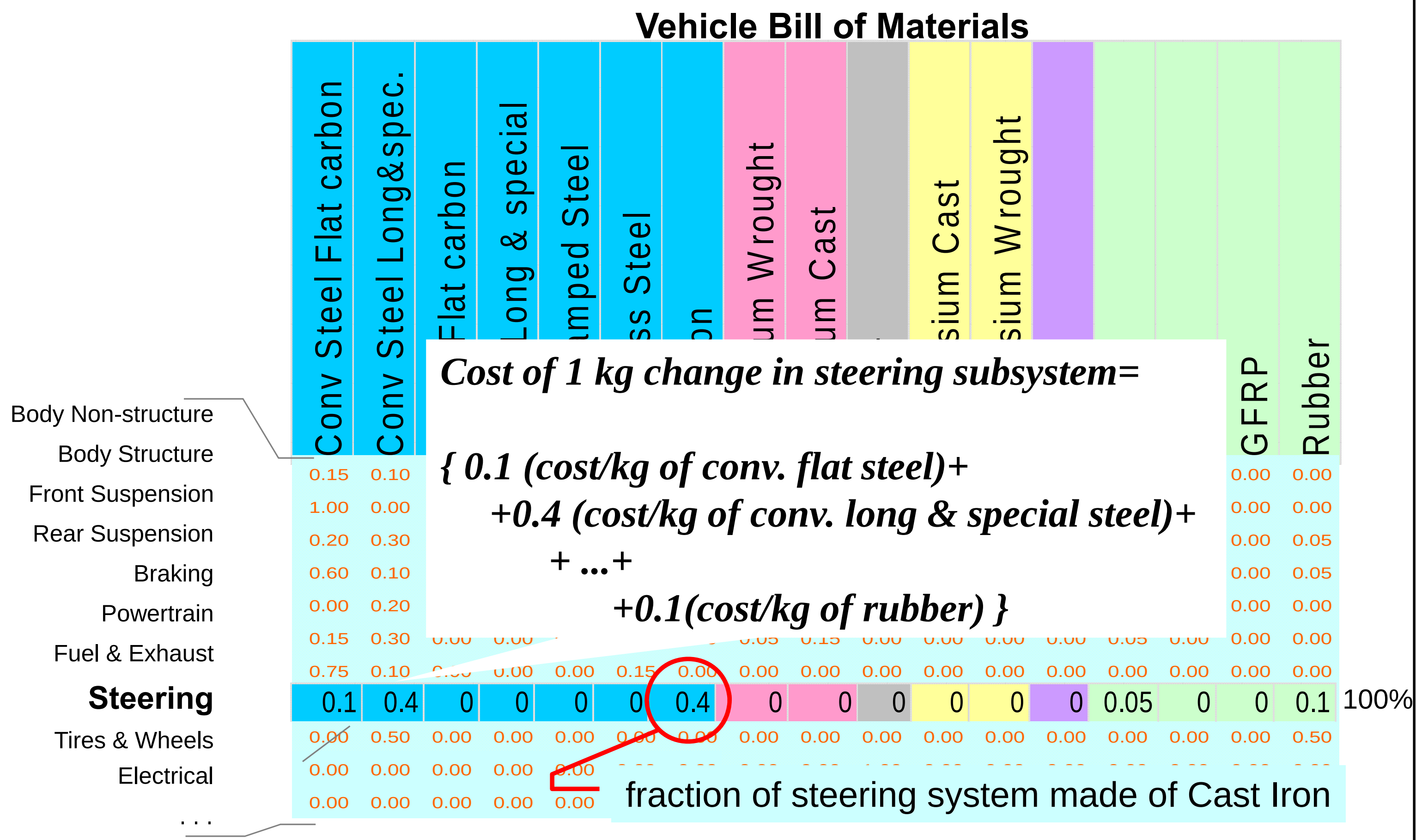
reasonable to assume machinery and tools will not change significantly



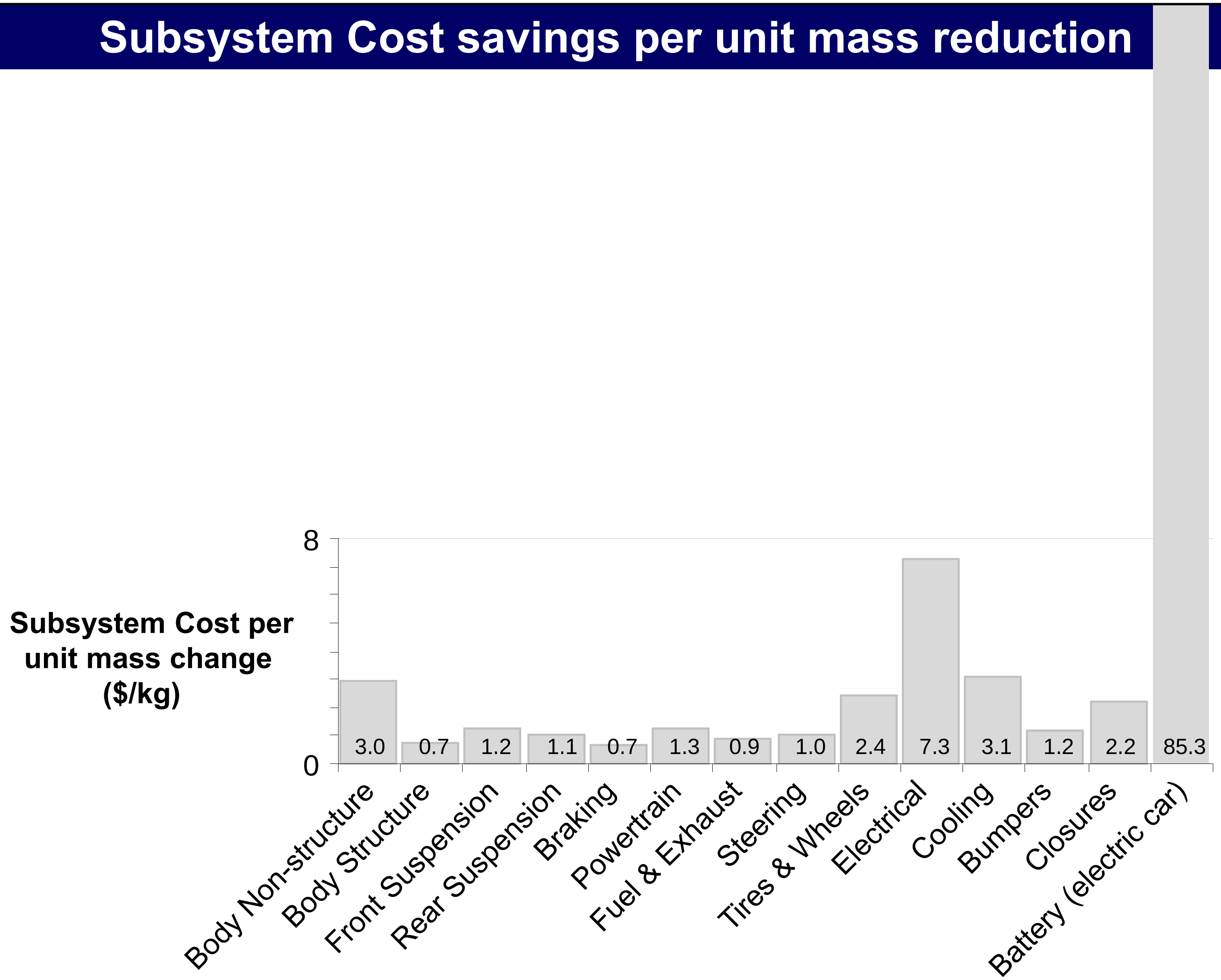
Subsystem resizing cost difference is due to change in cost of Materials in the subsystem

$$\Delta C = \Delta m \text{ (cost / kg for subsystem)}$$

Cost Modeling Secondary Changes



Subsystem Cost savings per unit mass reduction



The math

Vehicle Bill of Material and subsystem material cost

$$\bar{\alpha} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots \\ \alpha_{21} & \dots & \dots \\ \dots & \dots & \alpha_{ij} \end{bmatrix}$$

where

α_{ij} *=fraction of subsystem i composed of material j*

Note that rows will sum to 1

$$\bar{c} = \begin{bmatrix} c_1 \\ \dots \\ c_j \end{bmatrix}$$

where

c_j *=cost per unit mass of material j ($/kg)*

Material cost of subsystem i in vehicle

$$\bar{C} = \begin{bmatrix} C_1 \\ \dots \\ C_i \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots \\ \alpha_{21} & \dots & \dots \\ \dots & \dots & \alpha_{ij} \end{bmatrix} \begin{bmatrix} c_1 \\ \dots \\ c_j \end{bmatrix} = (\bar{\alpha})(\bar{c})$$

where

C_i *=total material cost of subsystem i in vehicle*

Battery Cost

Benchmark Cost

MAKE/ MODEL	TYPE*	ESTIMATED PRODUCTION DATE	TOTAL ELECTRIC RANGE (miles)	BATTERY CAPACITY (kWh)	PROJECTED PRICE	$/kWh	$/kg
Chevrolet Volt	PHEV	In production	35	16	$41,000	2562	397
Mitsubishi iMiEV	EV	In production	80	16	$40,000	2500	387
Nissan Leaf	EV	In production	73	24	$32,780	1365	210
Aptera 2e	EV	2011	20	21	$25,000–$45,000	1190-2143	184-332
BYD e6	EV	2011	250	48 or 72	$650/mo. lease		
Ford Focus	EV	2011	100	23	N/A		
Smart ED	EV	2012	85	16.5	N/A		
Tesla Model S	EV	2012	160/230/300	42/65/85	$56,500 and up	1345	208
Toyota Prius	PHEV	2012	13	5.2	N/A		
Volvo C30	EV	2012	90	24	N/A		

*Notes (vehicles table): *EV= electric vehicle (battery), PHEV= plug-in hybrid electric vehicle*
Sources: Sentech and manufacturers

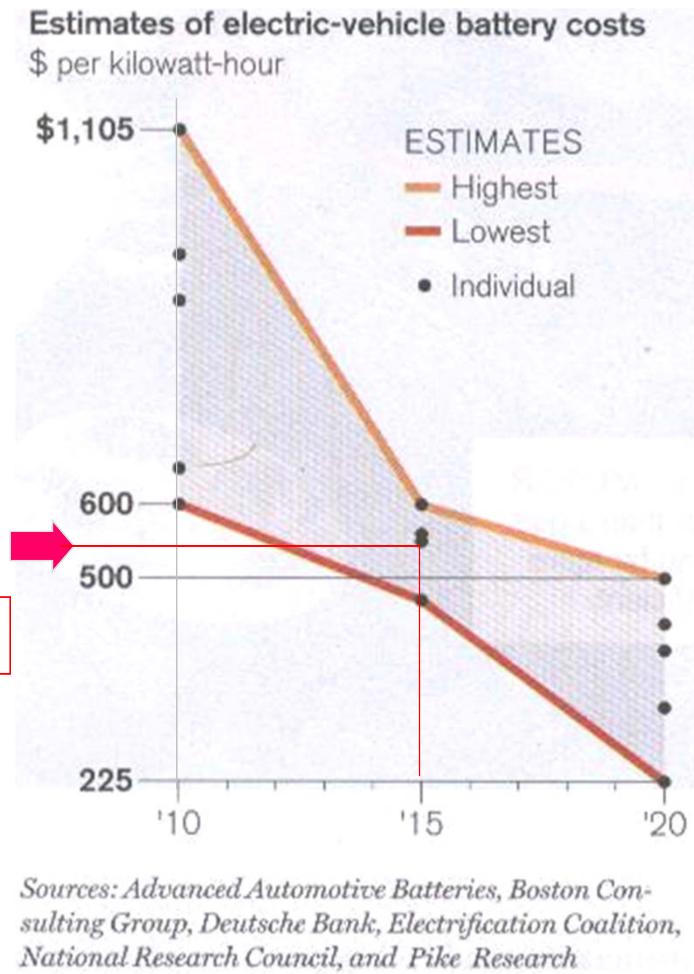
Notes (emissions chart): Coal figures are based on highest-emitting coal plants in 2010; natural-gas figures are based on new combined cycle plants in 2010. Source: Electric Power Research Institute, 2007

Technology Review, January/February, 2011, pg 61

Battery Cost

[$550 / kWh] [155 Wh/kg] [kW/1000W]

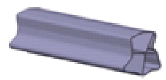
85.25 $ / kg



Technology Review, January/February, 2011, pg 61

Cost Correlation with FSV design alternatives

Future Steel Vehicle Design Alternatives having cost analysis

	Component	Design Alternative
	1. Rocker	Steel rolled formed closed Steel hydroform Aluminum extruded
	2. B Pillar	Steel rolled formed closed Steel hydroform Steel stamped Aluminum extruded
	3. Tunnel	Steel rolled formed open Steel hydroform
	4. Rear rail	Steel Hot stamped Aluminum stamped

Future Steel Vehicle Process Operations

Stamping	Extrusion	Hydroform
1. blanking	extrusion ★	bending
2. stamping-1 ★	straightening	preform
3. stamping-2 (holes, flanges)	holes, local forming	hydroform ★
4. trimming	trimming	trimming

★ *indicates primary shaping process used in Design Advisor*

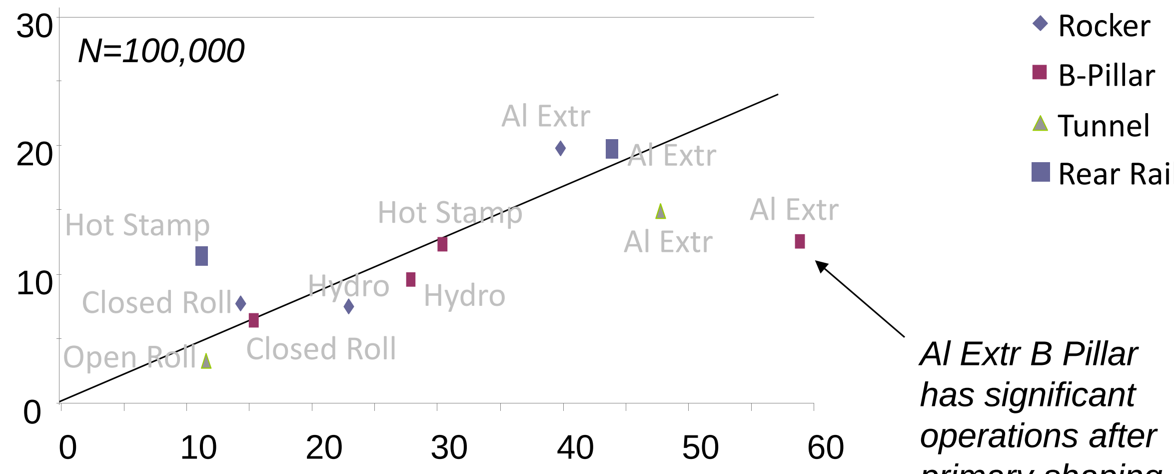
Cost Correlation-Absolute values

$C_{DETAILED} = 1.9C_{DA}$

$R^2 = 0.72$
σ=14.95

Design Advisor Part Cost

inputs: part mass, material, and process



Detailed analysis *FSV*

inputs: detailed process sheets

Al Extr B Pillar has significant operations after primary shaping increasing cost for detailed analysis

Pair-wise comparisons

Purpose of Design Advisor cost estimate is NOT for an absolute cost, but for an A-B RELATIVE comparison

		Alt. A $7	Alt. B 18	Alt. C 19
Alt. A	$7		11	**12**
Alt. B	18			1
Alt. C	19			

← estimate of absolute performance for each alternative

← performance of alternative in column (C) relative to alternative in row (A)

Better alternative is based on sign
For cost, lower is better so
+ choose row alternative
- choose column alternative

B-Pillar

		Closed 6.42	**Hot Stamp** 16.92	**Hydro** 15.82
Closed	6.42		10.5	9.4
Hot Stamp	16.92			-1.1
Hydro	15.82			

Column alternative worse

Column alternative better

Cost Correlation-Paired comparisons

Design Advisor

Rocker

		Closed	Hydro	Al Ext
		$7.83	18.11	19.8
Closed	$7.83		10.28	11.97
Hydro	18.11			1.69
Al Ext	19.77			

B-Pillar

		Closed	Hot Stamp	Hydro	Al Ext
		6.42	16.92	15.82	12.37
Closed	6.42		10.5	9.4	5.95
Hot Stamp	16.92			-1.1	-4.55
Hydro	15.82				-3.45
Al Ext	12.37				

Tunnel

		Open	Al Ext
		3.31	14.96
Open	3.37		11.59
Al Ext	14.96		

Rear Rail

		Hot Stamp	Al Stamp
		15.96	27.02
Hot Stamp	15.96		11.06
Al Stamp	27.02		

Detailed Analysis

FSV Report

Rocker

	Closed	Hydro	Al Ext
	14.27	22.88	39.78
14.27		8.61	25.51
22.88			16.9
39.78			

B-Pillar

	Closed	Hot Stamp	Hydro	Al Ext
	15.4	30.44	27.91	58.95
15.4		15.04	12.51	43.55
30.44			-2.53	28.51
27.91				31.04
58.95				

Tunnel

	Open	Al Ext
	11.56	47.78
11.56		36.22
47.78		

Rear Rail

	Hot Stamp	Al Stamp
	17.88	43.89
17.88		26.01
43.89		

9 out of 11 agree
(post processes not considered for these two)

N=100,000   row worse than column   row better than column

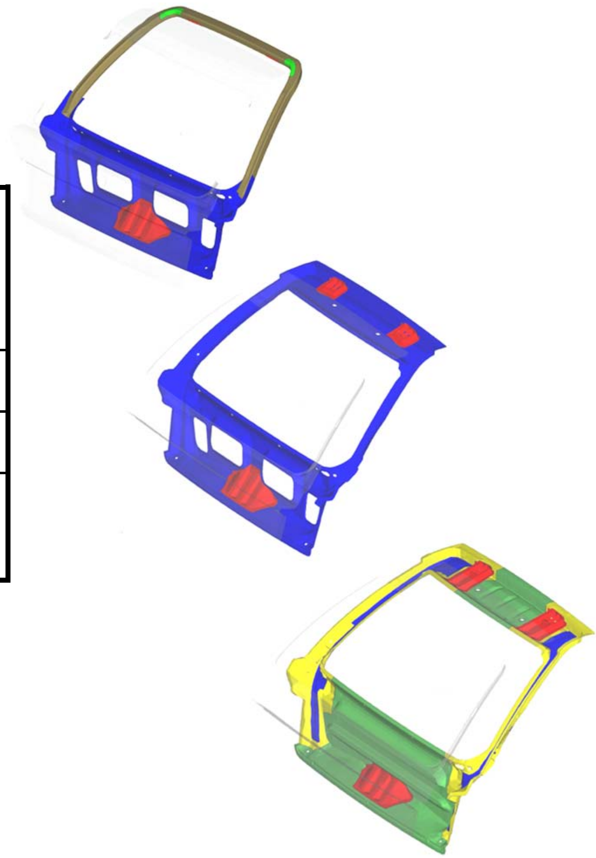
Case Study 3 – Hatchback closure Data

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

Results Summary – Hatchback closure

Material	Primary Process	Total Cost ($)	Total Mass (kg)	material cost ($/kg)
Steel-AHSS	Hydroform	53.12	7.81	1.1
Aluminum	Stamping	84.81	6.77	4.8
Sheet Molding Composite	SM Press	59.42	8.05	3.0

All hatchbacks have surface area=1.0 m²



Case Study 3 – Hatchback closure, Cost Analysis

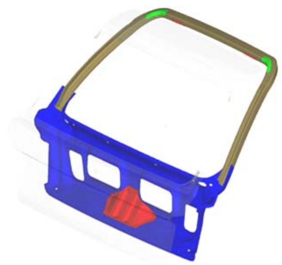
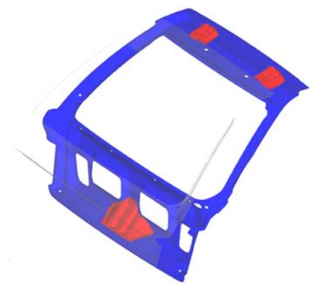
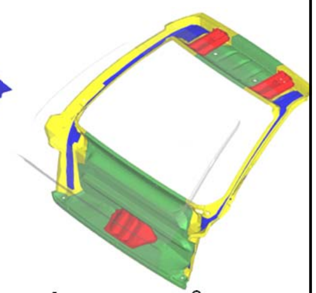
Plans for 20xx vehicle

Hatch door area=1 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: Hatchback closure

		
Area=1 m^2	*Area=1 m^2*	*Area=1 m^2*
Original Component	**Competitor 1 Component**	**Competitor 2 Component**
AHSS Hydroformed 7.81 kg	Aluminum Stamped 6.77 kg	SMC SM Press 8.05 kg

Case Study 3 – Hatchback door, Cost Analysis

Purpose: To examine cost analysis results, to see how batch size affects results, to change material cost per kg

Keep vehicle input data the same
1. Input component data for AHSS vs Aluminum hatchback
2. Go to Component Cost sheet and observe relative costs

Note: This comparison uses default material cost per kg values. The MIT paper used the following material costs AHSS=1.1 $/kg, Aluminum=4.8 $/kg, SMC=3.0 $/kg
To change these default values, go to the Solution Map sheet, select Instructions, scroll to bottom of instructions page and select Protection=OFF, click Return in upper right corner, select Cost for Part icon on Solution Map, go to cell C177. Here you will see a list of material cost. Change the three values to agree with the values in the MIT study. Scroll up to se the changed results

3. Record the costs for the AHSS and Aluminum hatchbacks
4. Go back and enter component data for AHSS vs SMC hoods
5. Observe and record the costs below
6. Change the batch size to 30,000 units and record results for AHSS vs SMC hoods

Batch size	AHSS hood cost (1.1 $/kg)	Aluminum hood cost (4.8 $/kg)	SMC hood cost (3.0 $/kg)
100,000			
30,000			

Case Study 3 – Hatchback closure, Cost Analysis

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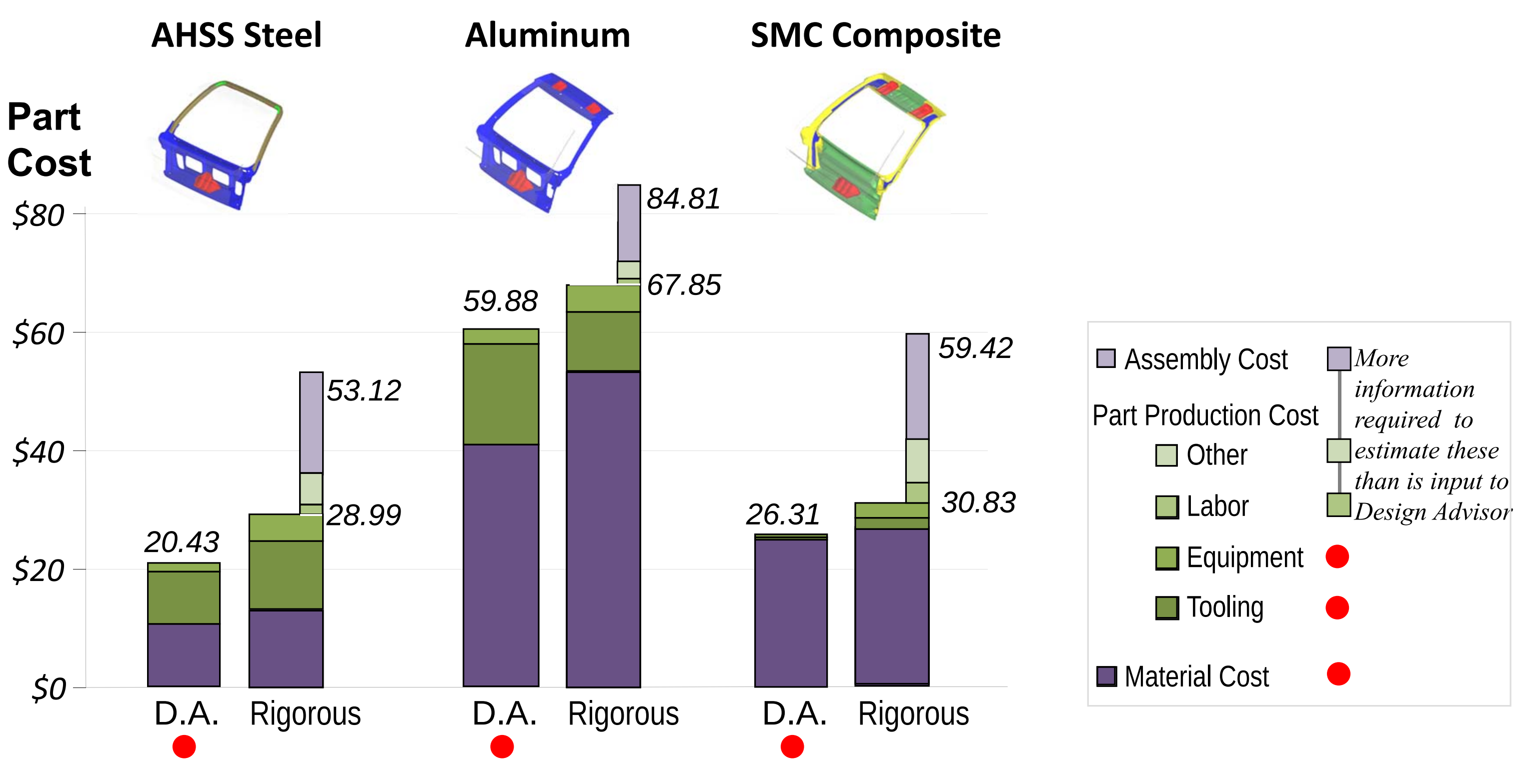
Batch size	AHSS hood cost (1.1 $/kg)	Aluminum hood cost (4.8 $/kg)	SMC hood cost (3.0 $/kg)
100,000	*20.43*	*59.88*	*26.31*
30,000	*36.53*		*27.09*

Case Study 3 – Hatchback door, Cost Analysis



Material cost 1.1/kg 4.8/kg 3.0/kg 100,000 parts

Lightweight Vehicle Consortium
J. Dahmus and R. Roth