**Estimation of Body Costs**

- Spreadsheet provided
  - Lotus 123 version
  - Excel version

- Basic Elements
  - 4 key body components
    - Roof
    - Rear Floorpan
    - Quarter Panel Inner
    - Quarter Panel Outer

- 3 Material Options
  - Steel
  - Aluminum
  - SMC

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Aluminum</th>
<th>SMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Rear Floorpan</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>QP Inner</td>
<td>OK</td>
<td>OK</td>
<td>NOK</td>
</tr>
<tr>
<td>QP Outer</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

- Material choices for key components propagate throughout entire BIW
Top-Level Spreadsheet Overview

Four criteria components

Body line inputs

Model output summaries

Material costs

Criteria Component Input

- Specification of component material is the sole input

- Collects necessary inputs from the "Inputs" Sheet and moves it to the appropriate process model:
  - Stamping for steel and aluminum
  - SMC molding for SMC
Quarter Panel Inner CANNOT Be SMC

- Selecting SMC will generate errors!

Body Line Inputs

<table>
<thead>
<tr>
<th>BIW Model</th>
<th>Inputs</th>
<th>Roof Stamp</th>
<th>Floor Stamp</th>
<th>OuterQ Stamp</th>
<th>InnerQ Stamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A0</td>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
</tr>
</tbody>
</table>

Basic Parameters

- Production Volume
- Wage Rate, Benefits and Overhead
- Capital Accounting Assumptions
## Model Outputs

<table>
<thead>
<tr>
<th>BIW Model</th>
<th>Inputs</th>
<th>Roof Stamp</th>
<th>Floor Stamp</th>
<th>OuterQ Stamp</th>
<th>InnerQ Stamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AE</td>
<td>AE</td>
<td>AC</td>
<td>AH</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Cost & mass of criteria parts

<table>
<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Weight</th>
<th>Part Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steel</td>
<td>26.91</td>
<td>$18.62</td>
</tr>
<tr>
<td>2</td>
<td>Aluminum</td>
<td>6.56</td>
<td>$57.61</td>
</tr>
<tr>
<td>3</td>
<td>Steel</td>
<td>12.45</td>
<td>$68.56</td>
</tr>
<tr>
<td>4</td>
<td>Aluminum</td>
<td>21.61</td>
<td>$89.95</td>
</tr>
</tbody>
</table>

**Total BIW Material Cost:** $233.78  
**Total BIW Fabrication Cost:** $814.60  
**Total BIW Weight:** 542.092 lbs

### Material & part type distribution

<table>
<thead>
<tr>
<th>Mass Fractions - Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>Aluminum</td>
</tr>
<tr>
<td>SMC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass Fractions - Part Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
</tr>
<tr>
<td>Type 2</td>
</tr>
<tr>
<td>Type 3</td>
</tr>
<tr>
<td>Type 4</td>
</tr>
</tbody>
</table>

### Cost summaries

<table>
<thead>
<tr>
<th>BIW Model</th>
<th>Body Line Cost Estimates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Labor Cost</td>
<td>$292.90</td>
</tr>
<tr>
<td></td>
<td>Capital Cost</td>
<td>$266.35</td>
</tr>
<tr>
<td>79</td>
<td>Total BIW Assembly Cost</td>
<td>$499.25</td>
</tr>
<tr>
<td>76</td>
<td>BIW Part Fabrication Cost</td>
<td>$814.60</td>
</tr>
</tbody>
</table>

**TOTAL:** $1,313.86
Problem: Which Materials?

- Vehicle BIW Composition is at your discretion
- Decision variables to consider
  - Vehicle Mass
  - Vehicle Cost
  - Recycling Targets
  - Fuel Consumption/Vehicle Efficiency
  - Production Volume
- Other factors
  - Cost to operate
  - Cost to recycle

Operating Cost Effects

- Focus on Fuel Economy
- Repair is a secondary effect
  - Data is limited, and highly proprietary
  - Insurance agencies
- Vehicle fuel efficiency depends upon
  - Vehicle Mass - F=ma
  - Vehicle Aerodynamics - Wind resistance
  - Vehicle Tires/Drivetrain - "Rolling" resistance
- Complex to predict
  - Driving cycles
"First Principles" Mass/MPG Calculation

Rule Of Thumb - 10-5 Rule

- A 10% Reduction In Mass...
- Yields A 5% Increase In Fuel Economy
- So, If A Baseline 3111 lb Vehicle Gets 21.6 mpg...

\[ \text{MPG} = 895.24 \text{ (mass)}^{0.463} \]
Third Calculation - DeLuchi

- Some Scaling Modifications:

\[ \text{Mass} = 2.015 \text{FE}^2 - 194.85 \text{FE} + 6375.54 \]

Rules of Thumb For Revenue & Landfill Expenses

- Cost of Landfill --- $120/ton
- Value of Ferrous Scrap --- $100/ton
- Value of Mixed Nonferrous Scrap --- $900/ton
- Separation Efficiencies --- 90% of ferrous recovered
  90% of nonferrous recovered
  rest goes to landfill

- Dismantlers Get Some Off Before The Shredder:
  50% of the Iron
  80% of the Stainless
  50% of the Aluminum
  25% of the Copper
  50% of the Glass
  50% of the Rubber

- This is a function of the kinds of parts made of these materials.

- For the purposes of this analysis, use the regressions to calculate the costs of the baseline vehicle. Then use the top 4 bullet facts to look at the impact of changes in the vehicle material composition.
### Baseline Vehicle Material Composition

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastics</td>
<td>224.5</td>
</tr>
<tr>
<td>Aluminum</td>
<td>155.5</td>
</tr>
<tr>
<td>Copper</td>
<td>49.5</td>
</tr>
<tr>
<td>Zinc</td>
<td>20.0</td>
</tr>
<tr>
<td>Lead</td>
<td></td>
</tr>
<tr>
<td>Other Ferrous</td>
<td>68.5</td>
</tr>
<tr>
<td>Iron</td>
<td>459.0</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>1387.0</td>
</tr>
<tr>
<td>HSS</td>
<td>234.0</td>
</tr>
<tr>
<td>Stainless</td>
<td>31.0</td>
</tr>
<tr>
<td>Glass</td>
<td>85.0</td>
</tr>
<tr>
<td>Rubber</td>
<td>134.5</td>
</tr>
<tr>
<td>Fluids</td>
<td>179.5</td>
</tr>
<tr>
<td>Other</td>
<td>83.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3111.0</strong></td>
</tr>
</tbody>
</table>

### Estimated Costs of Recycling Processing

- **Assumptions:**
  - Cost of Hulk - approx. $50
  - 70 ton/hr shredder
  - 8 hrs/day operation
  - 4 hrs/day maintenance
  - Transportation Costs - $0.10/ton/mi

- **Regression:** Cost / Vehicle

\[
\text{Cost} = -48.7820 - 0.0153F - 0.0079N - 0.0072U
\]

- **Where:**
  - \( F \) = Car Ferrous Mass (lbs)
  - \( N \) = Car Non-Ferrous Mass (lb) (not including lead)
  - \( U \) = Car Unrecyclable Mass (lb)
**Ferrous Metal Revenue - Estimated**

- Assumed
  - $100/ton shredded steel scrap
  - Standard Processing
- Regression Results From Cost Model
- Where (all in pounds):
  - \( F \) = total ferrous mass of car
  - \( N \) = total nonferrous mass (net of battery lead)
  - \( U \) = total mass of unrecyclable
- Result:-in dollars per vehicle
  \[
  2.2248 + 0.0376 F + 0.0055 N - 0.0068 U = \text{Ferrous Revenue}
  \]

**Non-Ferrous Metal Revenues - Estimated**

- More Detailed Estimate
- Recovery Rates of Aluminum, Copper, and Zinc Different
- Overall Mixed Metal Scrap Value Assumed At $0.45/lb
- Result-Dollars per vehicle:
  \[
  \text{Revenue} = 0.2025 \text{Al} + 0.3038 \text{Cu} + 0.4050 \text{Zn}
  \]
  - Where : \( \text{Al} \) = total aluminum in car
  - \( \text{Cu} \) = total copper in car
  - \( \text{Zn} \) = total zinc in car
- Note: Aluminum companies are being pressed to offer higher scrap values!
Landfill Cost Estimate

Assumptions:
- Landfill Cost - $120/ton
- Separations Not 100% Efficient

Results: Landfill Cost Per Vehicle

Cost = 6.9382 - 0.0018 F + 0.0041 N - 0.0574 U

Where:
- F = Car Ferrous Mass (lbs)
- N = Car Non-Ferrous Mass (lb) (not including lead)
- U = Car Unrecyclable Mass (lb)

Analysis of Problem

Necessary Analyses
- Costs of Production
- Costs of Operation
- Costs of Recycling

Variations
- Production Volume
- Material Costs
  - Lower Aluminum Costs?
  - Variations in Scrap?

Note Analysis Tops Out at One Assembly Plant - ~250,000/yr
- Third shift is expensive
Spreadsheet Mechanics

Starting Assumption:
- You all already know how to do sensitivity analysis in spreadsheets (Data Table???)
- Online Resource To Remind You Supplied On WWW Site

How To Do A Data Table When Varying Multiple Inputs?
- e.g., Four material specifications at a time?

Scenario Table Construction Combined With VLOOKUP()

<table>
<thead>
<tr>
<th>Case #</th>
<th>Rear FP</th>
<th>QP Inner</th>
<th>QP Outer</th>
<th>Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Scenario - 250,000 BIW/year

![Graph showing BIW Cost vs. Mass (lbs)]
Scenario - 50,000 BIW/year

Comparison of Scales

Massachusetts Institute of Technology
Cambridge, Massachusetts

Materials Systems Laboratory