Introduction to Cost Modeling, Template Overview for Performers

ARPA-E Tech-to-Market

February 12, 2014
Outline

‣ Context for Cost Modeling
  – Motivation, Definitions, and Examples

‣ Template Description
  – Scope, Overview, Worksheet Details

‣ Final Remarks
Part I

- Context for Cost Modeling
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Cost & Value

- **Production cost** (necessary but not sufficient by itself)
  - Willingness to pay (customer value)

→ *Value creation* potential of product
Full Business Financial Model

- Cash flow, dynamics of ramping production and varying sales, investments timing
- Similar information for other projects competing for resources → decision-making

Production / Operation Cost Model

- Determine resources (and $$) required for at-scale production/operation
- Tabulate material/component flow, labor & energy use, equipment, etc

Basic Materials & Process

- Bill of Materials (BOM) – list of “ingredients”
- Simple block diagram of production steps

Most performers aim for basic form of “Production Cost Model”
Cost Modeling Enables Research & Development

- Integrates calculations together for holistic consideration

- Identify cost drivers → steer research

- Communicate results with stakeholders
  - Internal: R&D, Management, Marketing
  - External: Industry Advisors, Investors, Customers, Licensing Partners
Modeling Benefits, Despite Uncertainty

Possible concern:
“It’s too early—there is too much uncertainty to calculate exactly how profitable this company/product would be.”

Modeling still beneficial:
- Make uncertainties explicit
- Identify most valuable improvements
- Develop targets, metrics
- Bound with theoretical limits
- Create thought framework for reducing uncertainties
Example Techno-Economic Analysis

Wave Energy Converters

- **Discovery**
  - Buoy contributes small portion of overall cost

- **Opportunity**
  - Enhance wave sensing → boost output, achieve competitive cost of electricity

Cost Modeling February 18, 2016

(Courtesy of Sea Engineering, Inc.)
Outline

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## Template Scope

### MODEL INCLUDES
- All major cost factors for production of saleable product
- Production model for bottom-up calculation of labor, material, and capital requirements to meet production volume
- Cost sensitivity and scaling analyses
- Estimated value of production project using sale price

### MODEL DOES NOT INCLUDE
- Operational details (e.g. schedule of work shifts)
- Minute product details
- Growth dynamics of business, production, or sales
- Company financial model (debt, equity, taxes, etc.)
# Template Worksheets

<table>
<thead>
<tr>
<th>#</th>
<th>Sheet Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Process Diagram</td>
<td>“Hand-drawn” block diagram</td>
</tr>
<tr>
<td>2</td>
<td>Results Summary</td>
<td>Displays key model inputs, outputs, essential analysis</td>
</tr>
<tr>
<td>3</td>
<td>Production Model &amp; OpEx</td>
<td>Step-by-step calculations: materials, labor, and production requirements</td>
</tr>
<tr>
<td>4</td>
<td>CapEx</td>
<td>Building, equipment, tools, etc.</td>
</tr>
<tr>
<td>5</td>
<td>Product Performance</td>
<td>Performance metrics, tied to production model if possible, supporting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>product value to customer</td>
</tr>
<tr>
<td>6</td>
<td>Financial</td>
<td>“Fully loaded” product cost, price, margin, payback period</td>
</tr>
<tr>
<td>7</td>
<td>Cost Analysis</td>
<td>Sensitivity analysis, step-by-step breakdown, scaling</td>
</tr>
<tr>
<td>8</td>
<td>Mass &amp; Energy</td>
<td>Supporting calculations regarding materials and processes</td>
</tr>
</tbody>
</table>
Capture the entire production process in easily understood format

- Descriptive step names and step-wise material inputs and outputs
- Establish modeling level of detail: each step to receive its own treatment in production model
- Overall inputs and output define position in value chain
Sheet 2: Results Summary

- Provides a quick-look at key model inputs and outputs
  - May choose to link inputs from this page to quickly run and show multiple scenarios
Builds up quantitative operating requirements for reaching desired production volume

- Calculate backwards: \[ \text{production volume} \rightarrow \text{throughput of last step} \rightarrow \text{throughput of second-to-last step} \rightarrow \ldots \rightarrow \text{throughput of first step} \]

- Requires definition of:
  - **Process-Step Properties**: \( \text{Batch Size}; \text{Cycle Time}; \text{Usage of Labor}, \text{Materials}, \text{Utilities}; \text{Yield} \), etc.
  - **Operational Availability**: \( \text{Days per Year} \), etc.

Tabulates consumption and production

- Materials/Components, Labor, Utilities, Product
- Calculates and implements required parallel production stations, step-wise
- Using cost rates, calculates all operating expenses
Batch definition grants flexibility

- Allows realistic, convenient units and conversion of units during steps
  - Units must match between steps; convert units from input to output within a step
  - For continuous process: maintain proportions, absolute values of materials and time can be arbitrarily small as needed

<table>
<thead>
<tr>
<th>ITEM</th>
<th>PROCESS VALUE</th>
<th>UNITS</th>
<th>CONSUMPTION/PRODUCTION</th>
<th>UNITS</th>
<th>COST/UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 - Make Dough &amp; Form Buns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flour</td>
<td>2000 g/batch</td>
<td>58027.2 g/day</td>
<td>$0.17/sandwich</td>
<td></td>
<td>e.g. material amounts for</td>
</tr>
<tr>
<td>Water</td>
<td>0.13 gal/batch</td>
<td>44.2 gal/day</td>
<td>$0.00/sandwich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yeast</td>
<td>36 g/batch</td>
<td>12744.0 g/day</td>
<td>$0.03/sandwich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>24 g/batch</td>
<td>8153.3 g/day</td>
<td>$0.00/sandwich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor (Direct)</td>
<td>1.5 workers/line</td>
<td>155.1 person/hr/day</td>
<td>$0.72/sandwich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>2 kwh/batch</td>
<td>680.3 kwh/day</td>
<td>$0.02/sandwich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Buns</td>
<td>12 buns/batch</td>
<td>4081.6 buns/day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle Time</td>
<td>0.3 hours/batch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required Gross</td>
<td>360.1 batches/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implemented No. Parallel Stations</td>
<td>18 prod lines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross Production Capacity</td>
<td>4267 batches/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line Utilization</td>
<td>80%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sheet 3: Production Model & OpEx (3/3)

(1) Step-wise Required Gross Production Volume

\[ GPV_i = GPV_{i+1} \times \frac{1}{Y_i} \times \left[ \frac{(Batch\ Input\ Quantity)_{i+1}}{(Batch\ Output\ Quantity)_i} \right] \]

- \( GPV_i \): batches per day (step \( i \))
- \( GPV_{i+1} \): batches per day (step \( i+1 \))
- \( Y_i \): Yield (e.g. 98%)
- \( \frac{(Batch\ Input\ Quantity)_{i+1}}{(Batch\ Output\ Quantity)_i} \): batch size conversion factor (must be same units)

(2) Parallel Production Required

\[ (Min\ Req'd\ Prod\ Lines)_i = \frac{GPV_i}{\left(\frac{Operating\ Hours}{Operating\ Day}\right) \times \left(\frac{Hours}{Batch}\right)_i} \times \frac{1}{Util_{MAX}} \]

- \( GPV_i \): batches per day per line
- \( \frac{Operating\ Hours}{Operating\ Day} \times \left(\frac{Hours}{Batch}\right)_i \): maximum allowed utilization (e.g. 85%)

(3) Labor Required

\[ Direct\ Labor = \frac{Workers}{Line} \times \#\ Lines \times \frac{Operating\ Hours}{Operating\ Day} \times Utilization \]

- \( \frac{Workers}{Line} \times \#\ Lines \times \frac{Operating\ Hours}{Operating\ Day} \times Utilization \): (person-hrs/day)

February 18, 2016
Sheet 4: CapEx

- Calculate capital expenditures
  - Equipment/machinery/tooling totals from per item price and number of stations
  - Estimated floor space needed from equipment sizes (rent is in OpEx)

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**Sheet 4: CapEx**

- **Calculate capital expenditures**
  - Equipment/machinery/tooling totals from per item price and number of stations
  - Estimated floor space needed from equipment sizes (rent is in OpEx)
Calculate/capture quantitative performance metrics

- Tied to production model if possible
- Metrics selected based on customer needs and segmentation of market → supports target price and production volume
- May expand sheet to model product operation → estimate value, willingness to pay

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### Sandwich Production Model 2013-12-20 - Microsoft Excel

#### Energy & Mass Density

<table>
<thead>
<tr>
<th>Energy Mass Density</th>
<th>2.2 cal/g</th>
</tr>
</thead>
</table>

#### Meat

| Mass of Slice | 20 g/slice |

#### Mass

| Mass Density | 20 g/sandwich |

#### Energy Mass Density

<table>
<thead>
<tr>
<th>Cheese</th>
<th>2.8 cal/g</th>
</tr>
</thead>
</table>

#### Cheese

| Mass of Slice | 20 g/slice |

#### Mass

<table>
<thead>
<tr>
<th>Energy Mass Density</th>
<th>4.2 cal/g</th>
</tr>
</thead>
</table>

#### Energy Mass Density

| Sandwich Size | 14 slices/sandwich |

#### Performance & Cost Metrics

<table>
<thead>
<tr>
<th>Energy Density</th>
<th>56 cal/bite</th>
</tr>
</thead>
</table>

#### Nutrition

| Customer Cost Effectiveness | 6.40 $/kcal |

**Note:**

- Values for Energy Density and Customer Cost Effectiveness are examples and may vary based on market research and customer feedback.
- The Energy Density value is determined to be important for target sectors, as more calories per bite supports a higher price.
- The Customer Cost Effectiveness value is discovered through primary research as market and customers impose constraints on this value; customer price per calorie must be below certain values or risk losing market segments either to direct competitors or to alternative food sources.
Sheet 6: Financial

- **Production project value calculation**
  - Capital Depreciation + OpEx → “Fully Loaded” Unit Production Cost
  - Price, Margin → Revenue → Profit → Payback Period

![Excel spreadsheet showing financial calculations](image.png)
A closer look at cost factors and uncertainties

- Single-variable sensitivity analysis: automatically calculate and display changes in fully loaded cost due to variation in model input variables
- Scaling of unit cost with production volume (including automatic re-calculation of OpEx and CapEx based on production requirements)
- Cost breakdown by production step and resource category
Calculations to provide or support values used in production model or product performance

- e.g. balancing chemical equations, thermodynamics, part count/mass derivation
- Housing calculations here maintains focus and clarity in other sheets
- (not populated in template)
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Final Remarks

- Get started modeling cost early, and refine as knowledge advances
  - guess as placeholder to get framework in place (and make note of it)
  - work on larger factors first (getting first significant digit right is a challenge)

- Use, manipulate, and adapt the template spreadsheet to suit your needs, but
  - be guided by its scope (deliberate)
  - don’t dodge necessary considerations because of difficulty to validate or seemingly unfavorable results

- Full business financial model (cash flow, debt, timing, etc.) also needed before pitching for external financing (not shown here)

- Send any cost modeling questions & comments to your ARPA-E Tech-to-Market Advisor
END
### Appendix: Matching Uncertainties (old)

#### Increasing Technology Readiness Level

<table>
<thead>
<tr>
<th>Data Inputs</th>
<th>Process Model</th>
<th>Price Inputs</th>
<th>Level of Detail</th>
<th>Capital Costing</th>
<th>Approximate effort</th>
<th>Review/Input</th>
<th>Cost Model Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-scale experimental data / conceptual prototype</td>
<td>Block Flow Diagram / Bill of Materials</td>
<td>Published prices, estimates based on similar products / processes</td>
<td>Major cost drivers only</td>
<td>Recognizing that it will have a required return</td>
<td>40 man-hours</td>
<td>Co-Worker Review</td>
<td>Focusing Research and Development Effort</td>
</tr>
<tr>
<td>Small-scale process unit data / &quot;Minimum Viable Product&quot;</td>
<td>Process Flow Diagram / BOM + rough schematic</td>
<td>Vendor discussions to inform major costs, estimates on others</td>
<td>Estimates of majority of operating costs and capital equipment</td>
<td>&quot;Rule of 72&quot; - 10% discount rate</td>
<td>200 man-hours</td>
<td>Several co-workers from varying disciplines</td>
<td>Developing research targets/goals</td>
</tr>
<tr>
<td>Pilot plant data / Scale Product</td>
<td>Process Simulation / Computer Aided Design</td>
<td>Vendor quotes for most equipment</td>
<td>90% of equipment and operating costs included as a line item</td>
<td>Discount rate based on variability of free cash flow with market</td>
<td>2,000 man-hours</td>
<td>Input from a potential investor under a NDA</td>
<td>Understanding long-term viability of the technology, pitching VC's</td>
</tr>
<tr>
<td>Demonstration scale data / For Sale Production</td>
<td>Simulation verified with operating data / Detailed CAD</td>
<td>Negotiated contract data</td>
<td>98% included and verified by an independent 3rd party</td>
<td>Full Weighted Average Cost of Capital with all Tax Shields included</td>
<td>5,000+ man-hours</td>
<td>Fully shared with EPC and bank, open to modification/scrutiny</td>
<td>Securing Bank Financing, projecting earnings, activity-based costing</td>
</tr>
</tbody>
</table>