Understanding Financial Risk Exposure in Manufacturing

Building new manufacturing facilities often involves high startup investments and presents learning challenges for the new operational staff. This is particularly true in many of the new clean energy development projects that are currently garnering both government and private investment funds. Success of these facilities requires the development of realistic financial models of manufacturing facility costs so that the operational team and the investors can set sensible goals and estimate investment profiles.

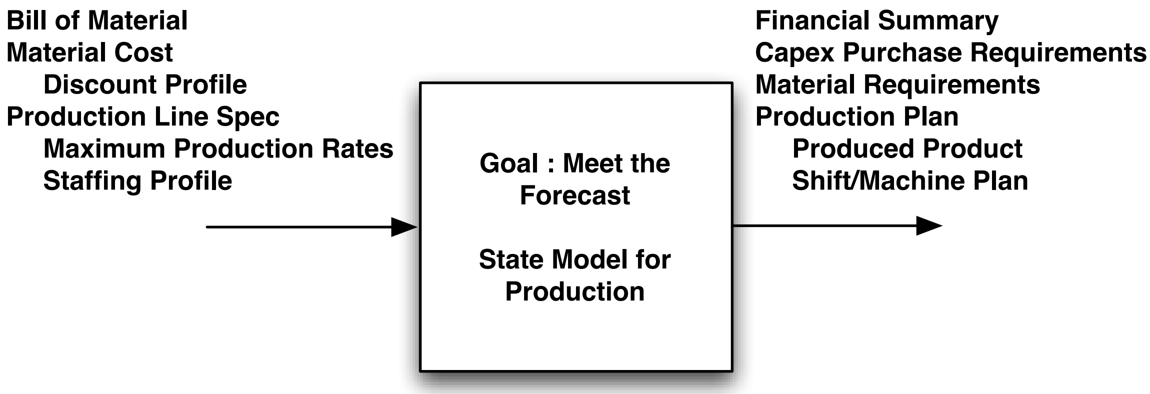
While there are a large number of excellent operational research tools and techniques for analyzing factory resources, they require specialized expertise and often are most applicable to stable factory systems for which the organization has already developed deep knowledge and experience. They are focused mostly on optimizing a specific aspect of the system. In addition, these tools and experts, if they exist, are frequently disconnected from the financial decision making process. In the absence of good modeling capability, entrepreneurs and new organization managers use simple excel models that often reflect the optimism and enthusiasm of the founders and ignore the potential variations in the process that may occur as the organization grows. This creates unrealistic expectations of the manufacturing planning and development teams and can result in missed production goals and poor use of investment dollars.

Growth planning for manufacturing must include realistic variations in the process. Some of these variations are part of the growth curve of the organization such as machine yields and some are beyond the control of the team - such as material cost fluctuations. These fluctuations can cause significant spikes in the required investment funds and put pressure on the financials of the organization if they are not properly accounted for. Building models that include variations for key elements of the production system allows the management team to set rational production goals and predict the influx of investment funds that are necessary as production ramps up.

A simple model for production planning is presented that allows for variations in production yields, forecasting and material costs. An example for a battery manufacturing facility demonstrates the variations in the financials for yield and material cost related variations.

Simplified Production Planning

A model for production planning is presented that follows the heuristics that would likely be used in a manufacturing startup process. The goal of the system is to meet the forecast. The inputs to the model include: an initial forecast, the unit level bill of material, production line definition with maximum production rates and staffing requirements for each machine, material costs and discount profiles, and hourly costs for operational staff.



Model for Production Planning

Estimation of yields, forecasted sales and material costs are created by defining a minimum, most likely and maximum value along with an accompanying confidence level. A distribution that reflects these estimates is created for each variable. The confidence level allows for creating a wider distribution of values across the minimum and maximum for the variable.

The core model creates random variables for the forecast, material costs and production yields. A quarterly state model for a time period of interest is initialized. This state model includes all of the machines, materials and staff. The system creates a simulation based on the estimated values of the variables, eg. specific machine yields and material costs, and determines the correct state model necessary for meeting demand with the estimated forecast, material costs and production yields. The simulation is run multiple times to generate an understanding of the impact of these variations on the production system.

A summary of capital equipment costs, material costs, operational costs and unit costs over the time period of interest is calculated for each simulation run. The minimum, maximum and most likely outcome for each financial measure is presented to the planner in order to understand the total cost of running the facility in the presence of the variations.

Example: Lithium Ion Battery Production[1]

An example for a lithium-ion battery plant is presented. The purpose of this production line is to produce anode and cathodes for the battery. An outsourced contractor is assumed for the cell assembly with a 98% yield and a $0.25 per cell assembly cost. The production line is composed of 13 steps:

Step	Machine	Max Production
Proprietary Process 1	Proprietary Machine 1	19,359,648
Proprietary Process 2	Proprietary Machine 2	2,903,947
Proprietary Process 3	Proprietary Machine 3	1,173,690
Proprietary Process 4	Proprietary Machine 4	57,480,192
Proprietary Process 5	Proprietary Machine 5	179,625,600
Cathode Dry Mix	Cathode Muller	2,903,947
Cathode Wet Mix	Cathode Mixer	967,982
Cathode Coating	Cathode Coater	300,432
Cathode Calendering	Cathode Calender	4,860,669
Anode Dry Mix	Anode Muller	2,903,947
Anode Wet Mix	Anode Mixer	904,365
Anode Coating	Anode Coater	334,131
Anode Calendering	Anode Calender	4,860,669

The limiting production steps are the anode and cathode coaters. They are also the most expensive to purchase, have the longest lead time and have a learning curve associated with their operation. Variations included in the model are focused on these yields of these two machines.

The bill of material for the battery is composed of 14 materials:

Material	Measure
Proprietary Material 1	kilogram
Proprietary Material 2	kilogram
Proprietary Material 3	kilogram
Proprietary Material 4	pound
NMC	kilogram
Acetylene Black	pound
Expanded Graphite-1010	pound
VGCF-H Fiber	kilogram
Kynar 761	pound
NMP	gallon
Aluminum Foil	meter
G5 Anode Graphite	kilogram
Oxalic Acid	gram
Copper Foil	meters

[1] In order to maintain confidentiality of the specific battery design some values associated with price, materials and processes have been omitted.

The two most expensive materials are Copper Foil and NMC. The costs of these materials have been known to fluctuate dramatically on the commodity market and can thus prove to add a significant variation in cost. In practice, contracts are introduced that will stabilize the cost impact on the organization, however, at the early stage of production when volumes are very low the organization has little negotiation power with the vendors and may have a difficult time reaching an optimum price point. The model presented includes variations on these two material costs.

Simulation Results

The four-year summary for this production line is shown in the table below. This represents the results of 1000 simulation runs. One can see that the capital equipment alone can vary from $15.7M to $19.5M. These variations occur as the yields on the coaters make an impact on the production. Unit costs can change from $1.70 to $1.93 due to material cost variations. The combination of these variations can add significant changes to the expected financial performance in these growth years.

Financial Measure	Min	Mode	Max
Total Capital Equipment Investment	$15,762,440.00	$17,579,196.00	$19,532,440.00
Total Material Costs:	$31,503,073.58	$35,174,691.24	$37,822,248.64
Total Operational Cost	$8,119,030.88	$8,383,771.81	$8,643,063.72
Total Production	27,329,921	27,442,976	27,720,178
Cost Per Cell with Cap Ex	$2.34	$2.46	$2.62
Cost Per Cell less Cap Ex	$1.70	$1.82	$1.93

The previous table presents the variations in individual measures in order to get a sense of the bounds on the financial impacts. However, there is correlation among the variables, therefore picking individual runs for analysis will give more insight into the variation in costs and expected outcomes.

Highest Capital Equipment : An arbitrary selection of a run with the highest capital equipment scenarios shows the significance of yield rates. As production continues with the goal of producing to forecast, tipping points occur where new equipment is required. The capital equipment investment total is $19,532,440.00. This accounts for a ending production line composed of 22 machines, including 4 cathode coaters and 4 anode coaters. The operational cost also increases as increased shifts are necessary on most machines.

The capital equipment, operational and material costs total to $63,725,958.55 over the four-year period. Material costs in this particular scenario come in over a typical run at $35,848,521.17 and an overall cost per cell of $2.56.

Lowest Capital Equipment: An arbitrary selection of a run with the lowest capital equipment yields a total capital equipment investment cost of $15,762,440.00. This production line ends in a 20 machine lineup, using only 3 cathode coaters and 3 anode coaters. Similarly, operational costs are lower in this case with a lower number of machines.

The capital equipment, operational and material costs total to $58,776,795 over the four-year period. Material costs in this particular scenario also come in over a typical run at $34,782,341 and an overall cost per cell of $2.40.

Typical Scenario: An average run would generate financials similar to the Mode column in the summary table. For example run number 2182 in the suite of runs generates a total capital equipment investment of $17,647,440with material cost of $34,316,890.00 and operational costs of $8,282,587. Total investments for this run come in at $60,246,918 with a final cost per cell of $2.43. The details of a typical scenario are presented in the following section.

Combinations of the variations create more dynamics as runs 902 and 904 generate the following details, in which the material costs overcome the effects of the manufacturing yields.

Run #	Capital Equipment	Materials	Operations	Total Costs	Production	Cost /Cell
902	$15,762,440	$35,601,134	$8,232,015	$59,595,589	27,384,202	$2.43
904	$17,647,440	$31,688,069	$8,292,271	$57,627,781	27,368,756	$2.36

These variations seen over 1000 simulation runs creates an operational variation from the minimum total cost of $57,281,078 to a maximum of $65,275,795 resulting in a swing of almost $8M and a cell cost variation of approximately $0.25 which can result in a $6M variation in cost.

		Total Operational	**Raw Cell Cost**
Run 164		**$65,275,795**	$52,693,683
Run 347	Good yields and average material costs	**$57,281,078**	$49,505,936
Run 144	High material costs and reasonable yields	$63,837,284	**$52,945,651**
Run 112	Low material costs and average yields	$57,592,356	**$46,685,177**
Variation		**$7,994,716**	**$6,260,474**

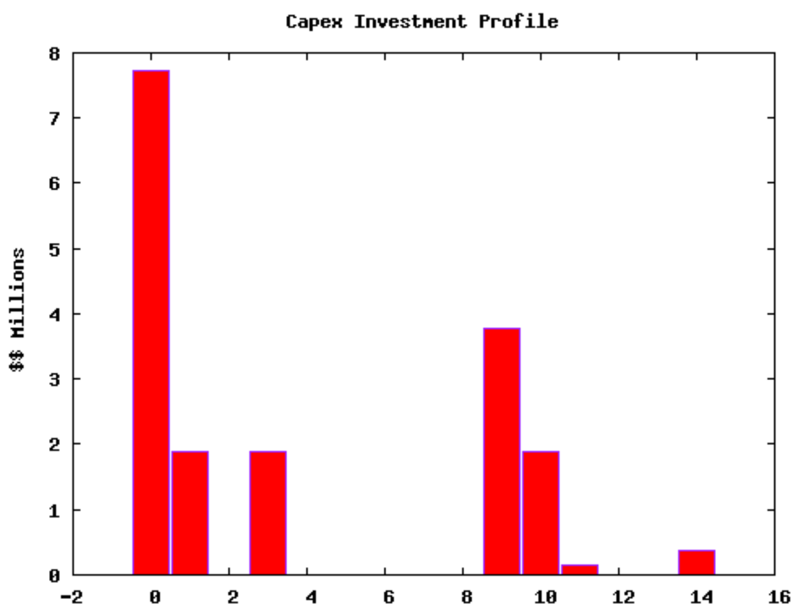
Typical Scenario Details

The results include the purchase schedule for the capital equipment so that management can plan appropriately for the expensive equipment purchases. All of the simulation runs require the purchase of an anode coater in the second quarter of

2010 and consequently, initial production line investment costs should consider the early purchasing requirements as these equipment purchases require a specified payment plan over the lead time prior to equipment delivery. The full investment profile is shown in the bar chart.

CapEx Purchase Schedule

Quarter	Machine	Equipment Cost
2010Q2	Anode Coater	$1,885,000.00
2010Q4	Cathode Coater	$1,885,000.00
2012Q4	Anode Mixer	$70,000.00
2012Q2	Anode Coater	$1,885,000.00
2012Q4	Cathode Mixer	$70,000.00
2012Q2	Cathode Coater	$1,885,000.00
2013Q3	Propriety Machine 3	$363,620.00
2012Q3	Anode Coater	$1,885,000.00



A yearly financial summary is presented for each year. An example of a first year summary is shown below. The cost per cell is at $11.66 in the initial start up year. Eg. First year financials

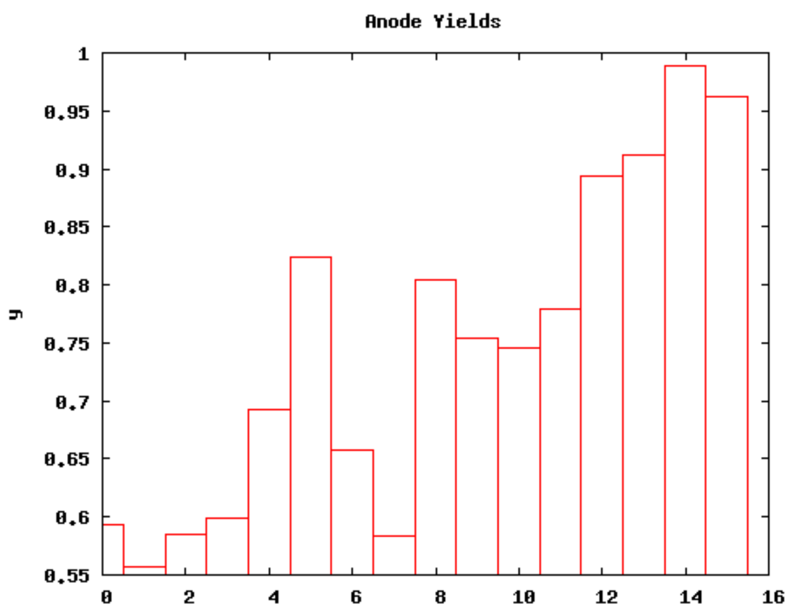
Total Capital Equipment Investment	$11,488,820.00
Total Material Costs:	$1,648,261.80
Total Operational Cost	$863,905.92
Total Production	1,226,548
Cost Per Cell with accumulated CapEX	$11.66

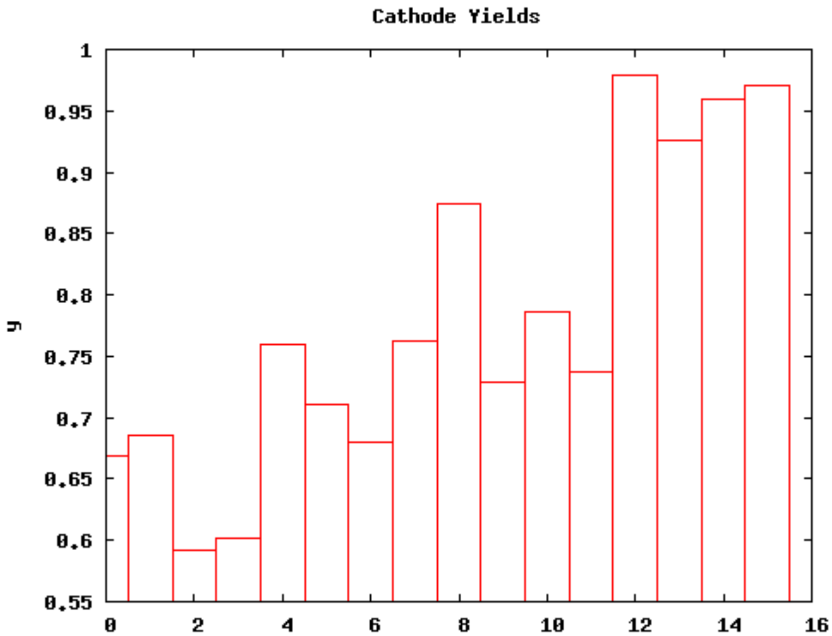
The material requirements are summarized for each year. The first year material requirements are shown below.

Eg. First year material requirements

Material	Amount	Measure
Material 1	2,315	kilogram
Material 2	255	kilogram
Material 3	291	kilogram
Material 4	6,216	pound
NMC	12,516	kilogram
Acetylene Black	1,554	pound
Expanded Graphite-1010	401	pound
VGCF-H Fiber	50	kilogram
Kynar 761	2,753	pound
NMP	9,387	gallon
Aluminum Foil	245,310	meter
G5 Anode Graphite	8,886	kilogram
Oxalic Acid	48,812	gram
Copper Foil	258,139	meters

The variations created for the yields of the anode and cathode coaters are shown below. These include a ramp up associated with the learning curve of the operational staff.





The four-year production plan is created along with the inventory levels for each quarter.

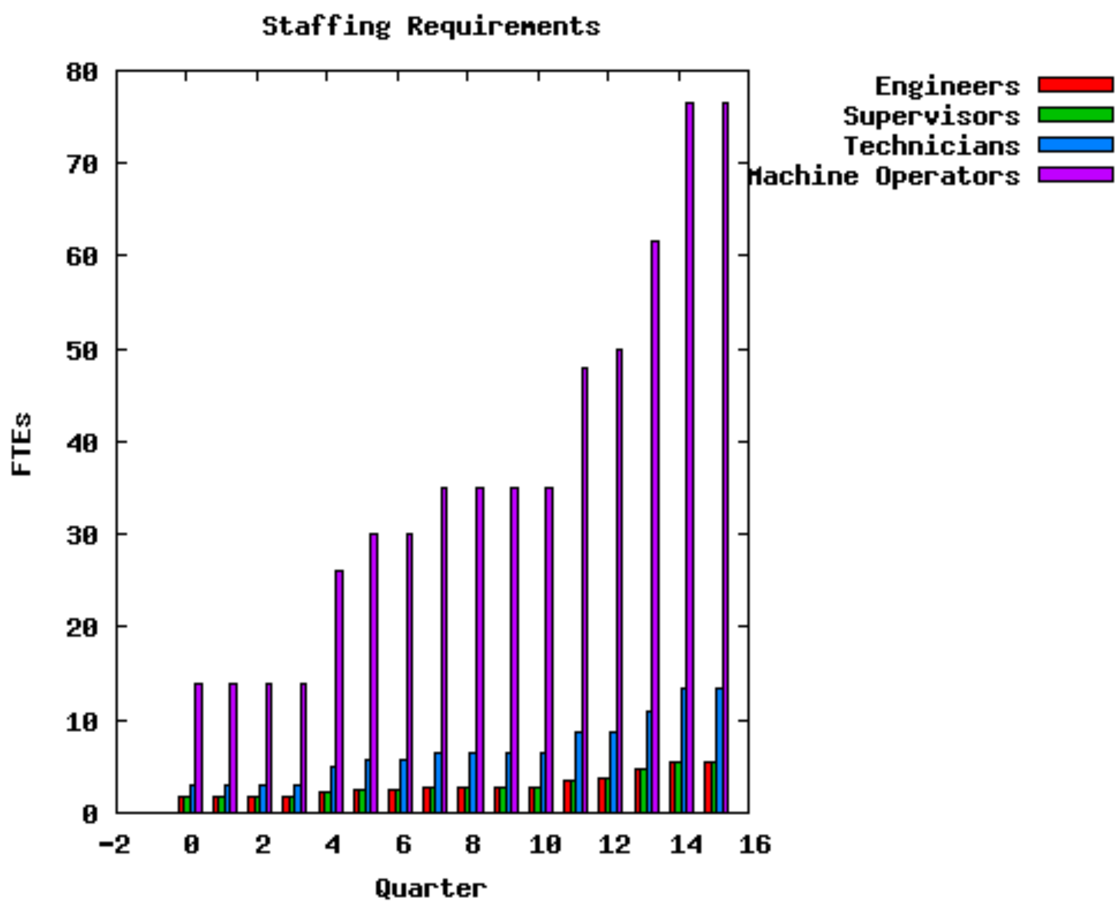
quarter	forecast	inventory	product build
2010Q1	9,120	295,662	304,783
2010Q2	56,760	553,147	314,245
2010Q3	303,900	555,583	306,336
2010Q4	755,300	126,500	326,218
2011Q1	946,500	84,365	904,365
2011Q2	1,134,500	93,058	1,143,190
2011Q3	1,254,000	12,748	1,173,690
2011Q4	1,254,000	378,240	1,619,490
2012Q1	1,354,000	670,455	1,646,220
2012Q2	1,554,000	666,416	1,549,960
2012Q3	1,574,000	441,252	1,348,840
2012Q4	2,474,600	313,575	2,346,920
2013Q1	2,847,600	179,070	2,713,100
2013Q2	3,581,600	108,588	3,511,120
2013Q3	4,393,600	206,071	4,491,080
2013Q4	4,393,600	334,296	4,521,820

The staffing and production line profile is also created for each quarter. For example, the table below demonstrates the increases in shifts necessary and the inclusion of a new anode coater in the second quarter of 2011. Note that this was indicated earlier in the capex purchase requirements as an anode coater purchase in the second quarter of 2010 account with a 1 year lead time.

Step	# of Machines	Yield	Material Cost	Shifts
Propriety Process 1	1 machines	0.99	$113,494.00	1
Propriety Process 2	1 machines	0.99	$3,808.64	1
Propriety Process 3	1 machines	0.75	$16,919.50	1

Propriety Process 4	1 machines	0.99	$0.00	1	
Propriety Process 5	1 machines	0.99	$0.00	1	
Cathode Dry Mix	1 machines	0.99	$276,415.00	1	
Cathode Wet Mix	1 machines	0.99	$106,762.00	2	
Cathode Coating	1 machines	0.710683	$78,423.00	3	
Cathode Calendering	1 machines	0.99	$0.00	1	
Anode Dry Mix	1 machines	0.99	$213,211.00	1	
Anode Wet Mix	1 machines	0.99	$213,303.00	2	
Anode Coating	2 machines	0.824144	$455,557.00	3	1
Anode Calendering	1 machines	0.99	$0.00	1	

The four-year staffing profile is generated that shows the composition of staff necessary to manage the production line for the four-year growth period. This indicates a requirement of almost 80 machine operators, over 10 technicians and 5 supervisors and 5 engineers.



Conclusions

Running single simulations at the outer edges of the estimated variables, eg. the minimum and maximum of a machine yield, can be done to bound financial results in simple models for a single variable. However, it is a very limited approach because running models with multiple sources of variations quickly becomes a combinatorial problem and overwhelms the simple modeling approach. This system runs multiple simulations across the estimated values of yields and material costs in order to produce a view of the production requirements in the presence of all of these variations.

In the example presented, a variation of over $8M in operational costs alone is estimated during the four-year startup phase. The results of such an analysis provides a view of the potential financial impacts that the organization could experience that are rarely included in a static financial analysis. The analysis is meant to *inform* the investors and management team and provide a *realistic investment planning profile*.