Evaluating Economic Feasibility and Design of Modular Production Systems in the Steel Industry

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Sponsor: GenH

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Agenda

1. Project Goal and Objectives
2. Design Baseline
3. Economic Analysis: P&L
4. Monte Carlo
5. Linear Program
6. Summary and Takeaways
7. Recommendations for Future Projects

Project Goal and Objectives

Goal: We aim to explore the concept of modular production systems in the steel industry through a hypothetical design model, determine the economic feasibility of the design, and create a precedent for processes in the future.

Objectives:

1. Explore what a modular production system could look like in a defined scenario and set of assumptions, using prophetic data to help illustrate a model of a MPS in a steel industry.
2. Determine the economic feasibility of implementing a steel-producing MPS on the basis of a positive net profit margin and ROI.
3. Identify risks, categorize and minimize potential points of failure in MPS and their potential impacts on the optimal supply chain.

Methodology

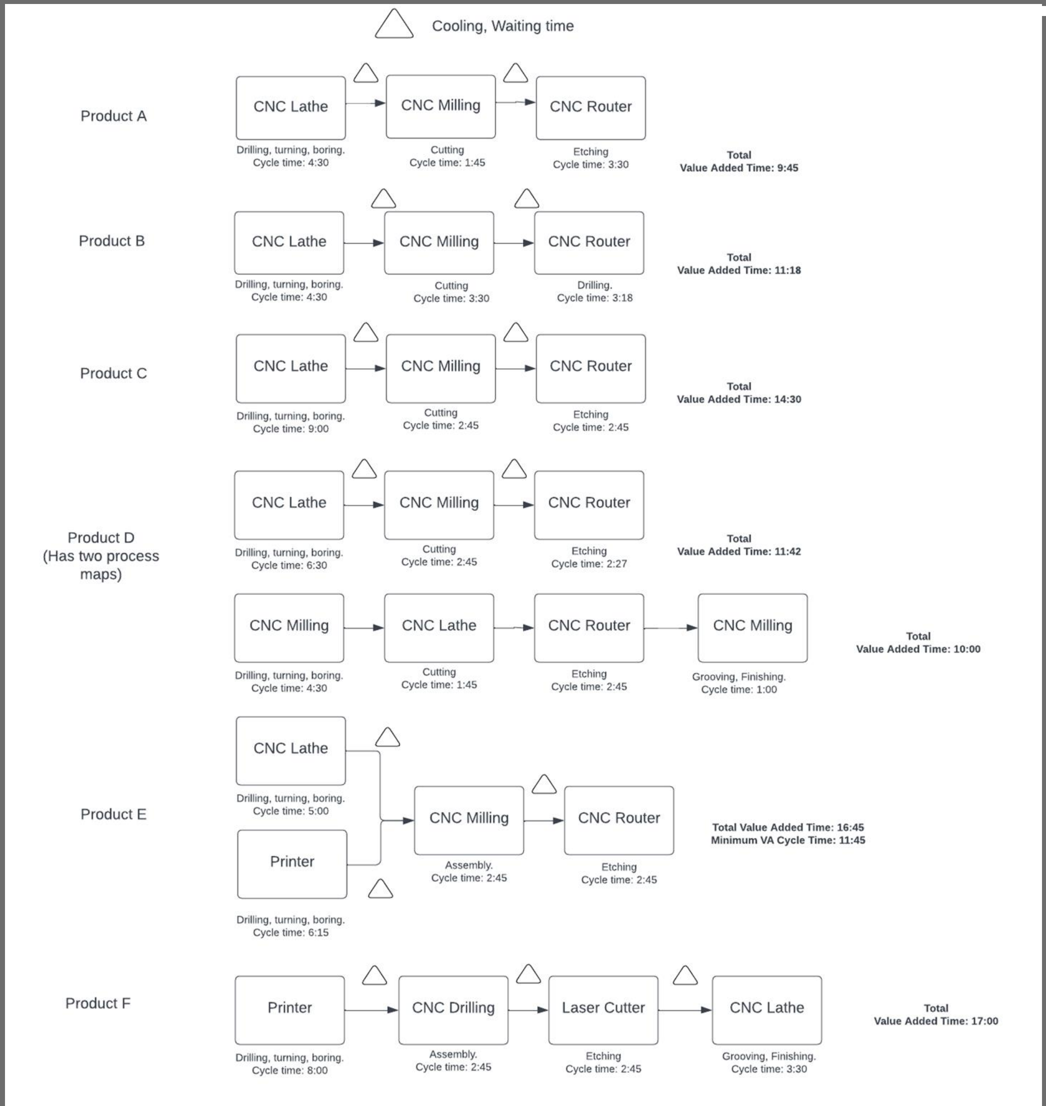
- Method 1:
  - Modular Production System Design (O1)
- Method 2:
  - MPS Implementation (O1,O2)
- Method 3:
  - MPS Analysis (O2 and O3)
  - Profit and Loss (O2)
  - Monte-Carlo (O2, O3)
  - Linear Programming Model (O2, O3)
  - Risks (O3)

№	Modularization Drivers	
1	Cost	Total cost
2		Material cost
3		Labor cost
4		Capital cost
5		Cost of operation
6		Disposal cost
7	After sales	Repair and maintenance
8		Upgrading
9		Adaptation
10		Modification
11		Recycling
12	Design and Development	Carry-over
13		Time to market
14		Product planning
15		Technology change
16		Multiple use of functional carrier
17		Technology push
18	Variance	Different specifications
19		Market variance
20		Use variance
21		Styling
22	Manufacturing	Common unit
23	Manufacturing	Tools and methods
24		Manufacturing process
25		Workforce management
26		Automatization
27	Assembly	Assembly process
28		Assembly time
29		Assembly organization
30		Education for assembly
31	Quality	Separate testing
32		Service life
33		Core competency
34	Supply chain	Global supply
35		Availability and reliability
36	Functionality	Functional purity
37		Functional variety
38	Sales	Lead time
39		Revenue
40		Distribution process
41		Distribution organization
42		Market segmentation
43		Market size
44	Ecology	End-of-life
45		Environment friendly

Modular Production System: Scenario Baseline

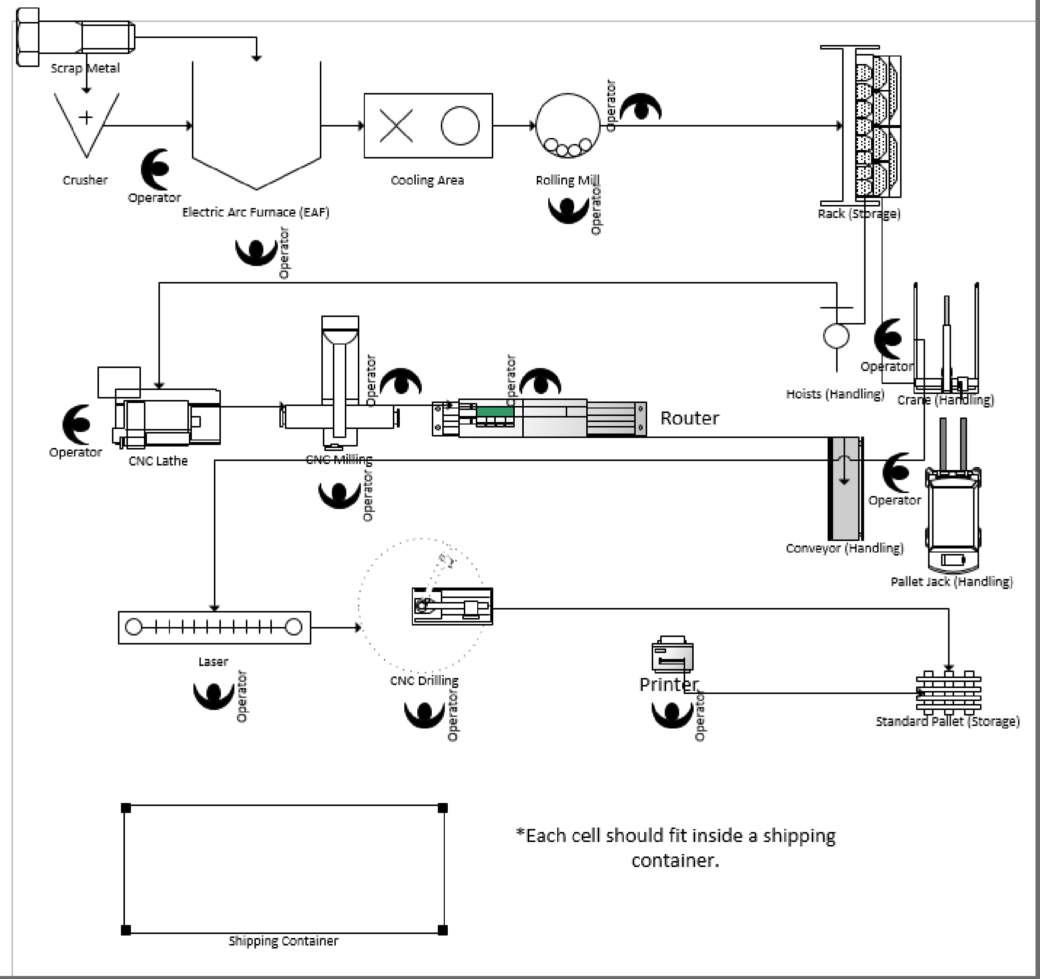
1. The MPS facility will operate for 16 hours a day, 7 days per week (340 days in a year).
2. Cells are standardized and identical.
3. All products are designed for manufacture (DFM) for the identical cells.
4. Each product is produced at various rates, summing to 90-95% of “full production”.
5. Machines and equipment will be financed at consistent rates.
6. No maximum of machines and equipment.
7. Raw materials are purchased as needed.

Process Map for Products



- This is a process map which shows the requirements for our products
- Each Product has a unique lead time and requires different processes to be completed
- New products can be added as long as their requirements can be satisfied with current machines

Hypothetical Layout



- An example of a cell Layout in the factory.
- Compact cells that can fit in one or multiple containers
- Stop or start production at a moments notice.
- The Machines in a cell should be easily replaceable to accommodate a different product

P&L Tables

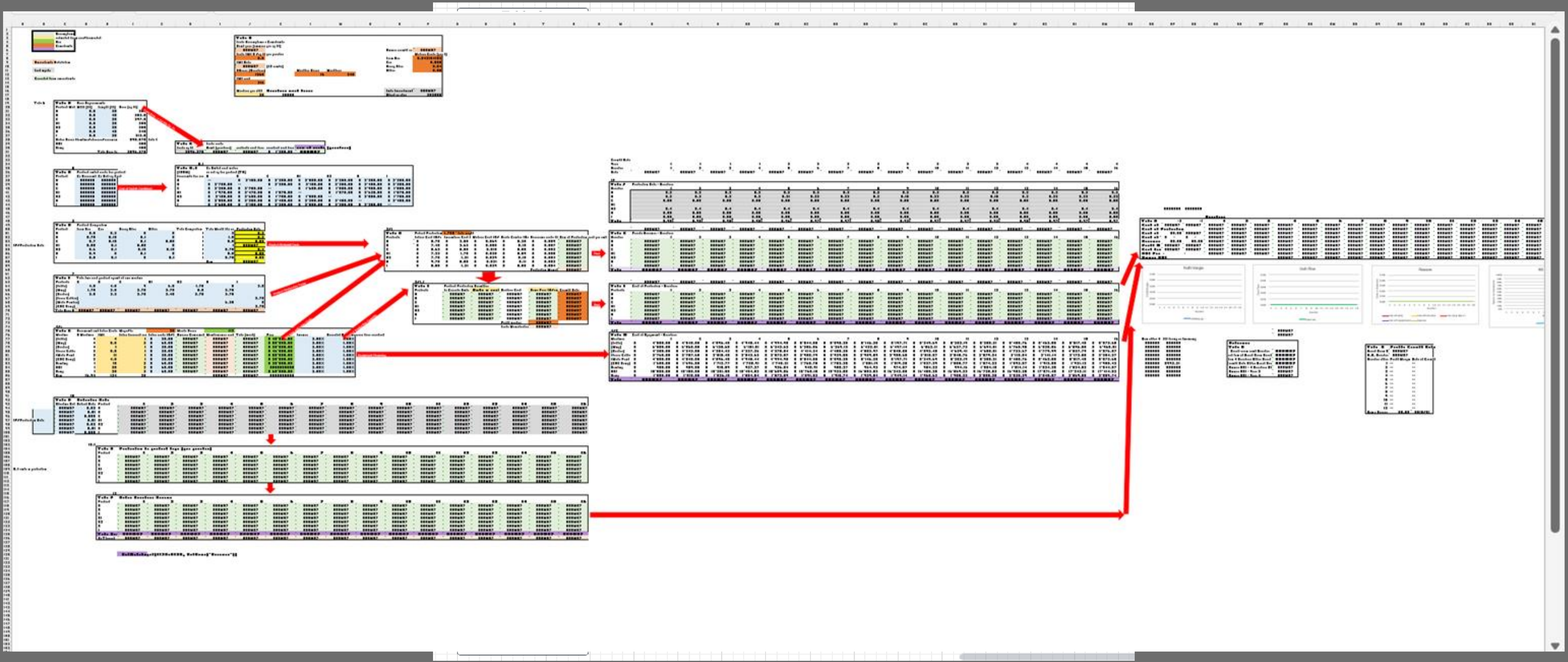
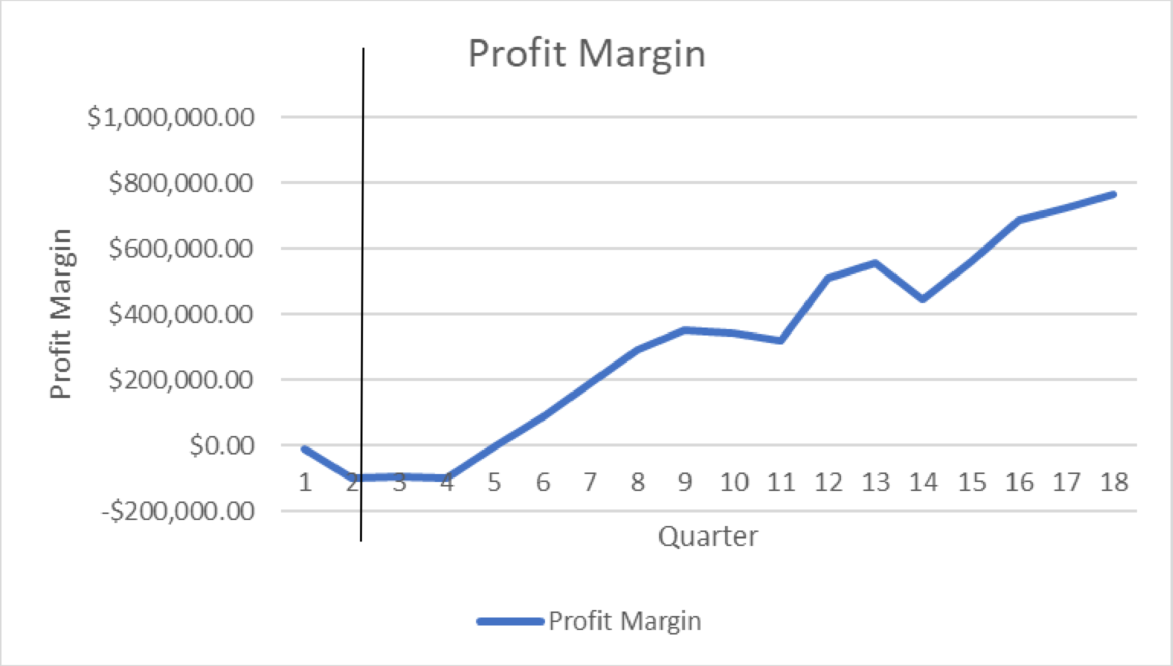
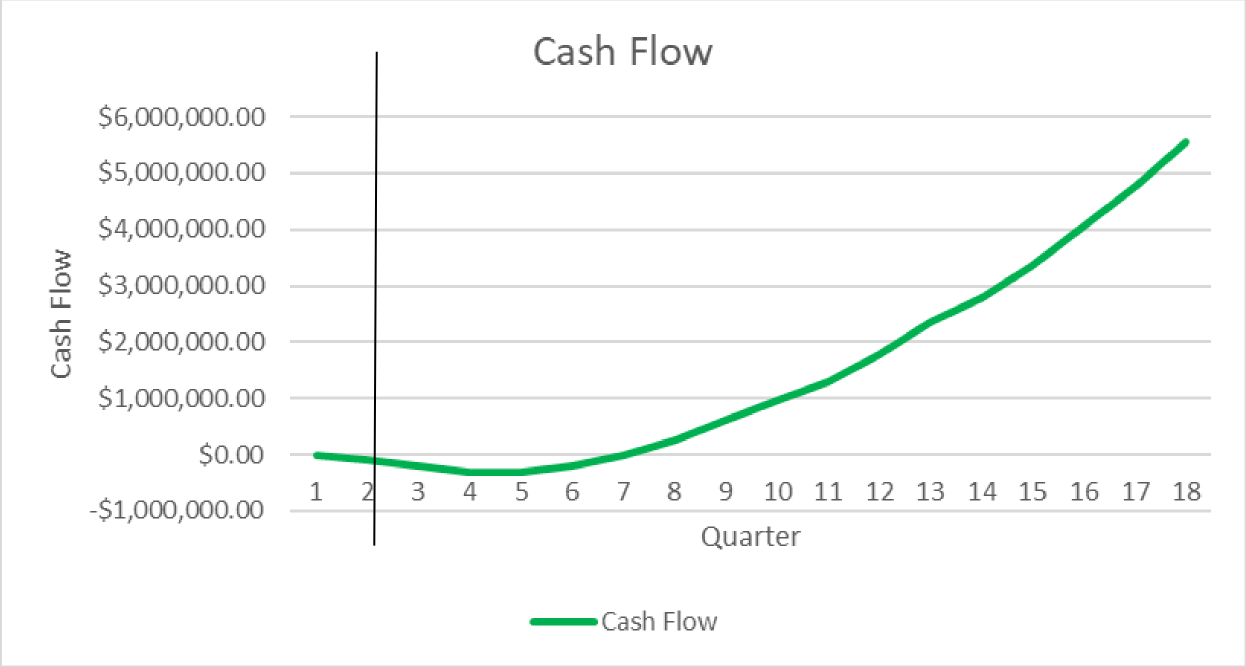


Table Q: P&L Summary

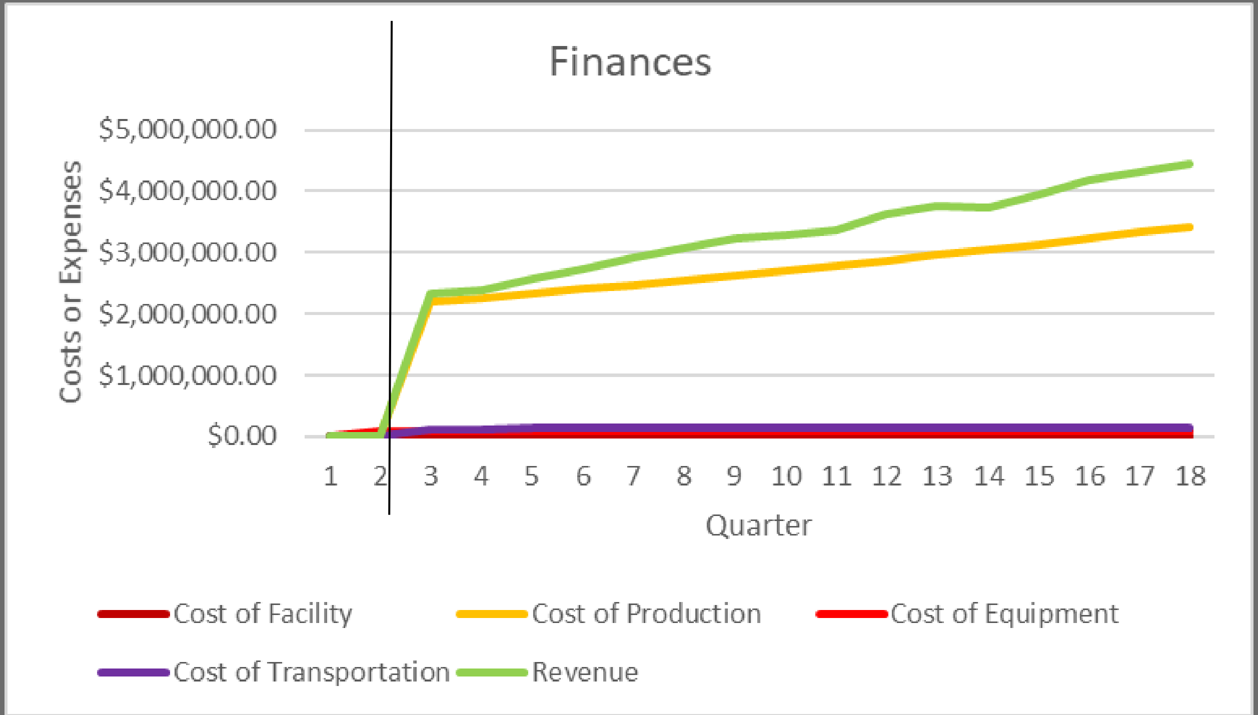
Quarters	-2	-1	1	2	3	…	16
Cost of Facility	$8,927.61	$9,199.50	$9,768.36	$10,065.85	$10,372.41	…	$15,319.84
Cost of Production	$0.00	$0.00	$2,214,180.37	$2,265,070.64	$2,333,022.76	…	$3,041,488.49
Cost of Equipment	$0.00	$87,687.96	$87,687.96	$88,107.36	$88,530.95	…	$48,691.04
Cost of Transportation	$ -	$ -	$ 121,461.75	$ 126,900.00	$ 131,306.25	…	$151,882.50
Revenue	$0.00	$0.00	$2,337,890.65	$2,392,197.05	$2,562,792.28	…	$3,600,596.65
Profit Margin	-$8,927.61	-$96,887.46	-$95,207.79	-$97,946.81	-$440.10	…	$343,214.78
Cash Flow	-$8,927.61	-$105,815.07	-$201,022.86	-$298,969.67	-$299,409.76	…	$872,904.57
ROI	-	-	-290%	-383%	-383%	…	5134%

P&L for Modular Production System





P&L for Modular Production System



Year (Quarter)	1 (6)	2 (10)	3 (14)	4 (18)
ROI	-303%	-547%	191%	98%

Accounting for Uncertainty in the Economic Model

Monte Carlo Simulation:

Output Statistic turns into an Output Probability Distribution

Fixed Inputs →

Variable Distributions →

Output Statistic Definition→

@RISK 8.2

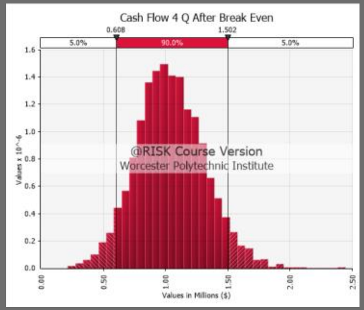
→ Output Statistic Distribution

→ Sensitivity Analysis (variables)

- Number of Iterations and Simulations
- Monte Carlo Random Number Generation

$786,369.08

Output Statistic → Output Distribution



Monte Carlo - Simulation

Output statistics:

1. Break even point (quarter)
2. Cash flow one year after break even point
3. Average growth rate of profit margin after break even point
4. ROI one year after break even point
5. ROI after 3 years of production

Uncertainty variables:

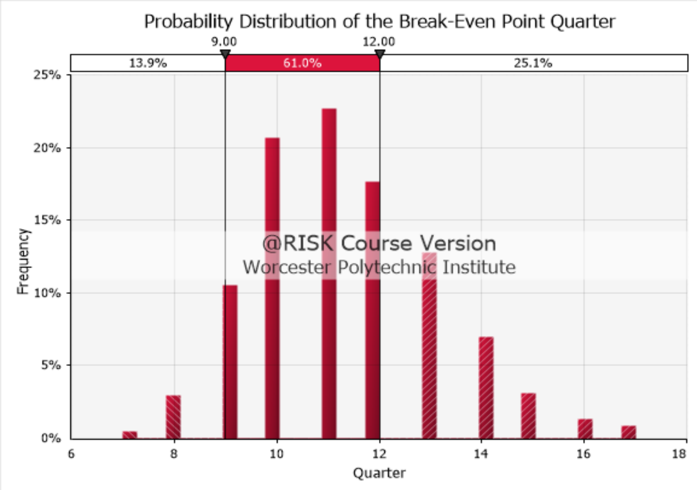
1. Rent price
2. Cost of kWh rate
3. Total value-added time (per product)
4. Machine maintenance costs
5. Facilities overhead markup
6. Manufacturing overhead markup
7. Sell through rate (per quarter)

Distributions:

1. Normal
2. Triang
3. Normal
4. Normal
5. Triang
6. Triang
7. Normal

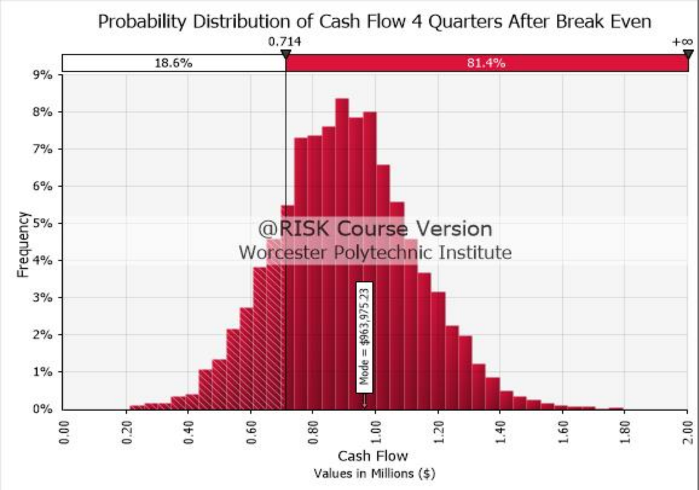
Distributions of the Output Statistics

What actually matters?



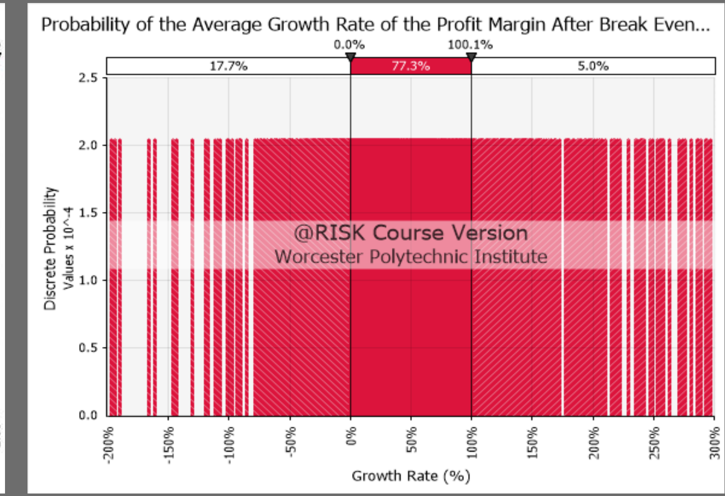
(1)

75% of samples broke even by year 3 of production



(2)

81% of samples have at least $714k cash flow within a year of breaking even



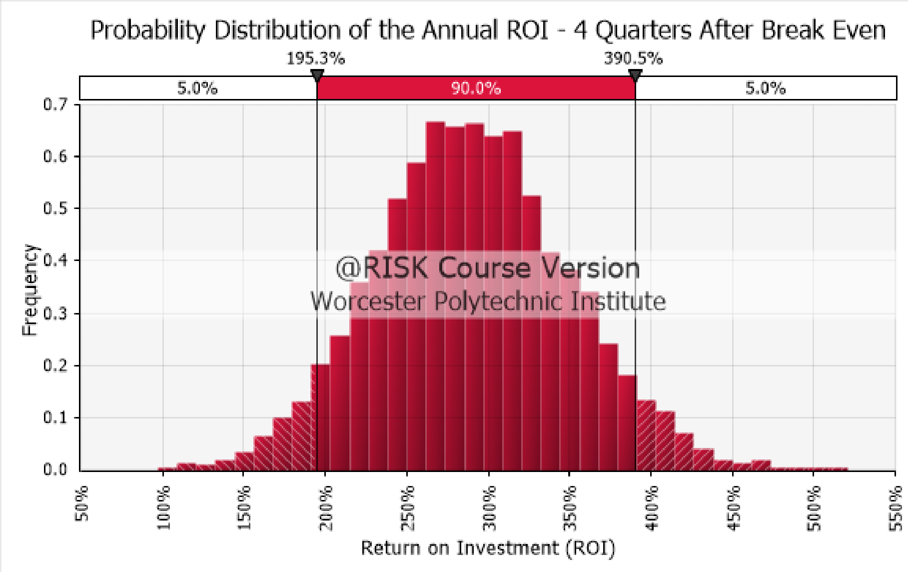
(3)

Profit margin from quarter to quarter is varies considerably and is unpredictable due to sell-through

Note: Simulation uses prophetic data, for example: product and labor data.

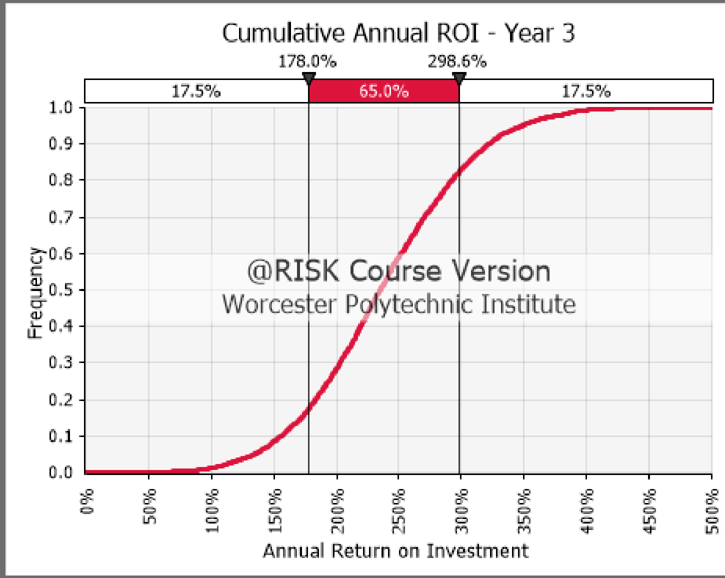
Distributions of the Output Statistics (pt. 2)

What actually matters?



(4)

90% of annual ROI between 195% and 390%



(5)

82.5% of samples have an annual ROI of at least 178% after 3 years of production

Note: Simulation uses prophetic data, for example: product and labor data.

Monte Carlo: Analysis of MPS Characteristics on Economic Trends

Versatile machine set →

→ Quick and cheap product switching

→ which means following demand and market needs

→ Higher sell-through

→ and means less overproduction

→ Higher sell-through and selling price, lower inventory costs

→ Quick and cheap product start up

→ which means lower product development risk

→ More (versatile) demand

→ and underserved market

Modular, DFM process →

(Does not require building a factory)

→ Quick start to production (Lower initial costs) →

→ Less capital required, quicker returns

→ Higher ROI, lower break even

→ Lower risk, full flexibility in location

→ Flexibility in electricity costs, lease cost, labor cost, etc.

Monte Carlo Takeaways

- Fairly confident that the modular production system will
  - **Break even before the third year** of production and
  - The **annual ROI will be greater than 178%**.

- With good process data, we could get a great idea of the economics of a MPS in steel
  - Then we could model scenarios like the Covid-19 pandemic.

Sensitivities:

- Sell-through makes or breaks the system.
- High machine maintenance costs (*need real data)
- Product value-added time (*need real data)
- Manufacturing overhead rate (*need real data)

Linear Programming Objectives

Objective:

- Maximize the revenue to encourage cell switching and changes of product production in the economic recession of 2008-2009

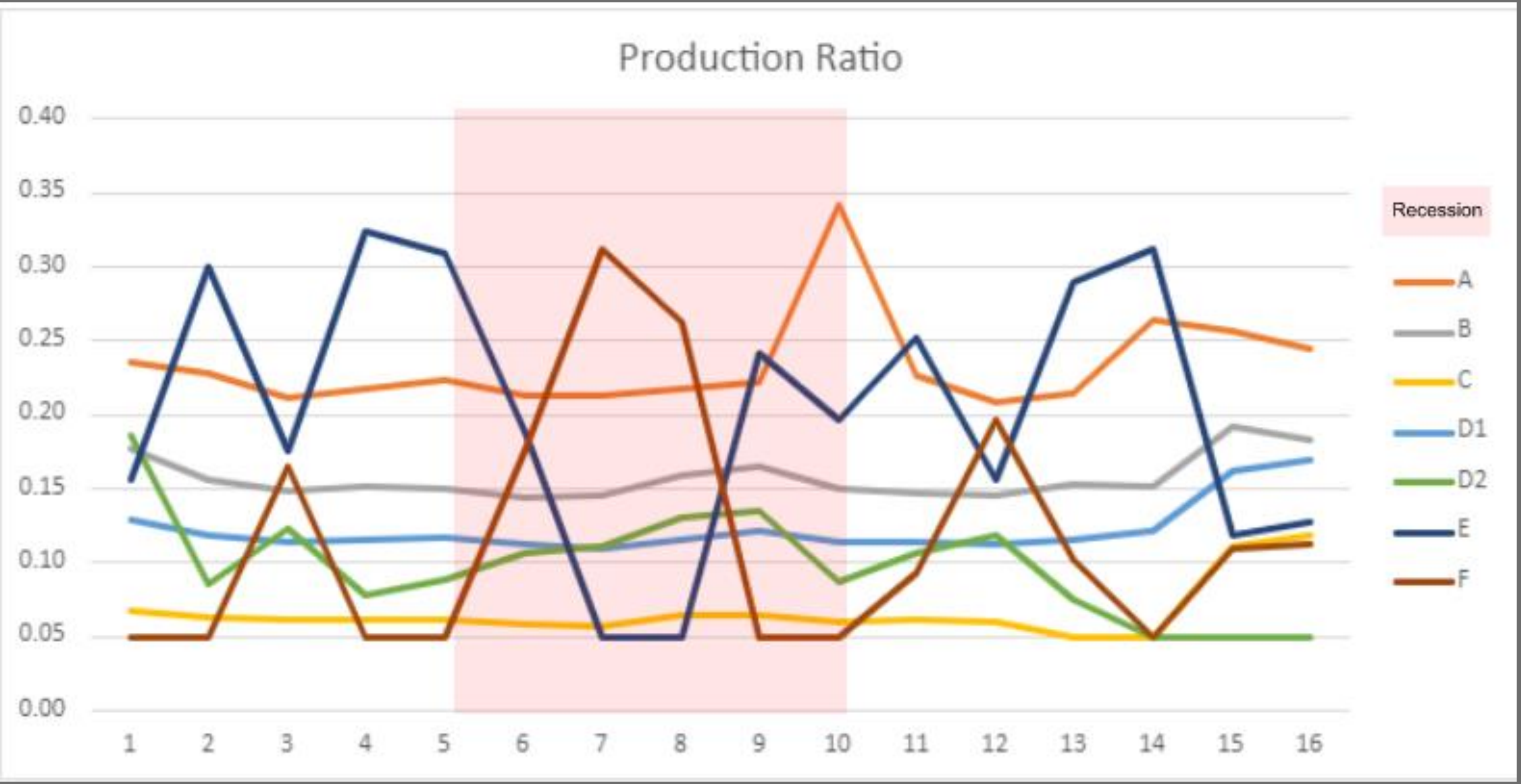
Constraints:

- Minimums and Maximums of product production ratio
- Electricity Maximums
- Labor Maximums

Goal:

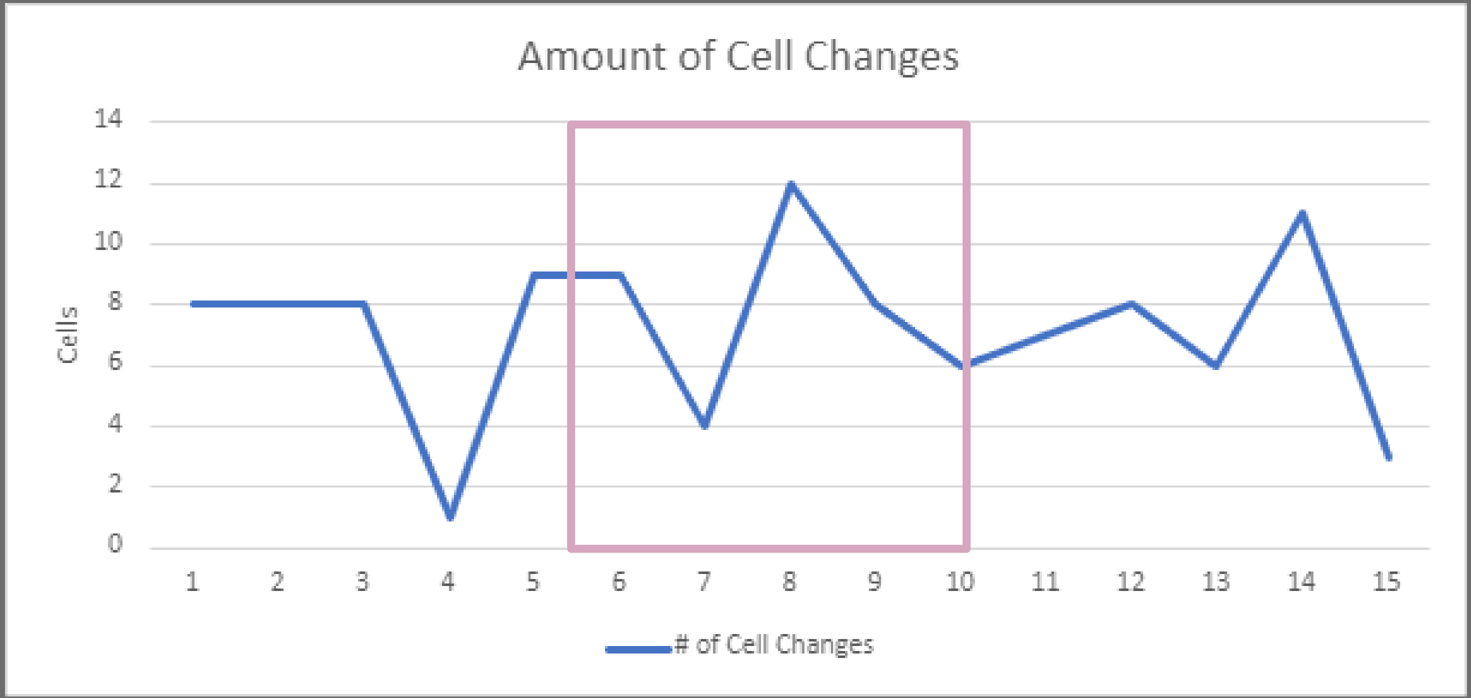
- Observe the reactions of production changing
- Observe the functionality of cell switching

Linear Program Optimization



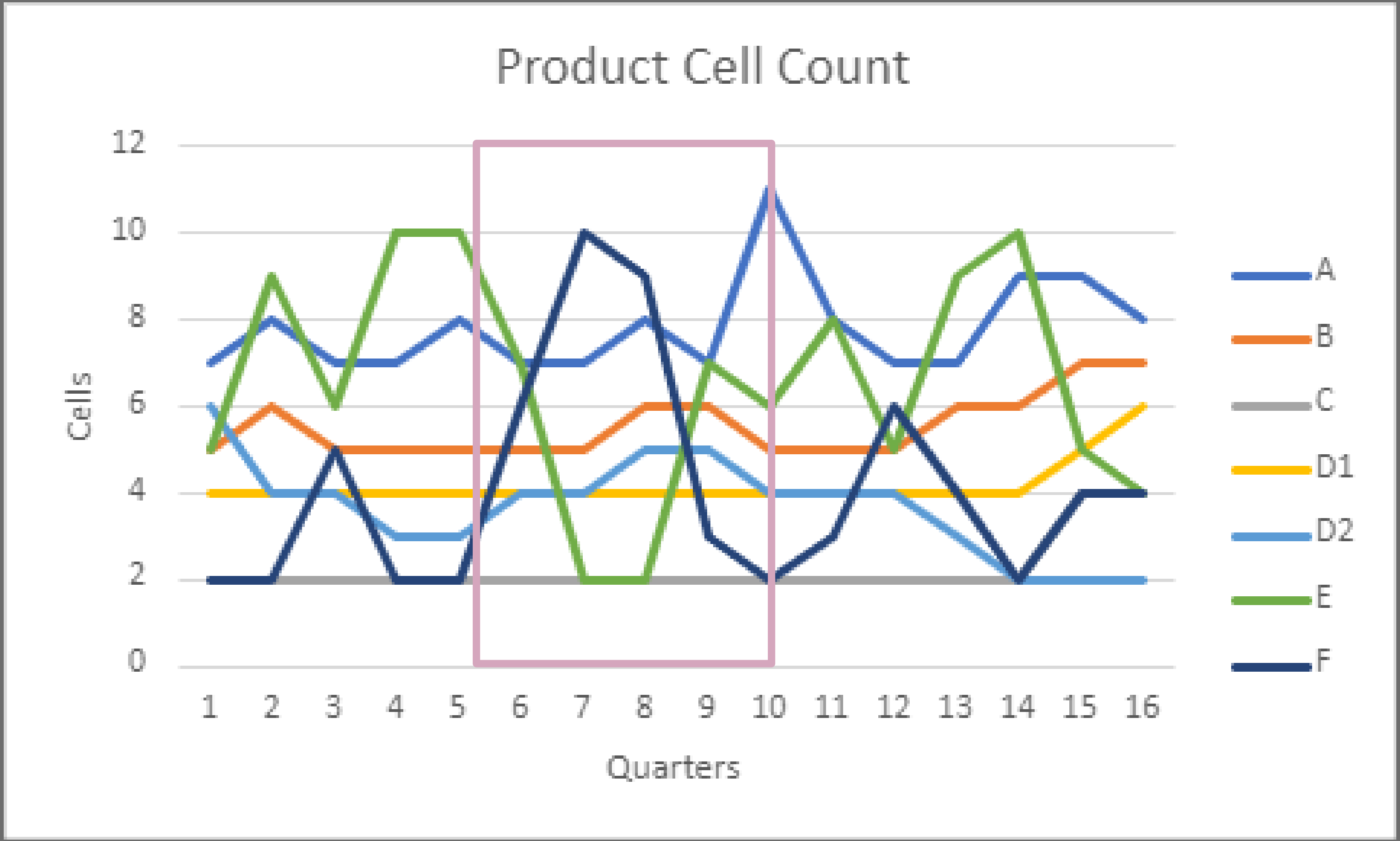
Linear Program Optimization

The program utilized the production, inventory and constraints to create the number of cells needed for production.

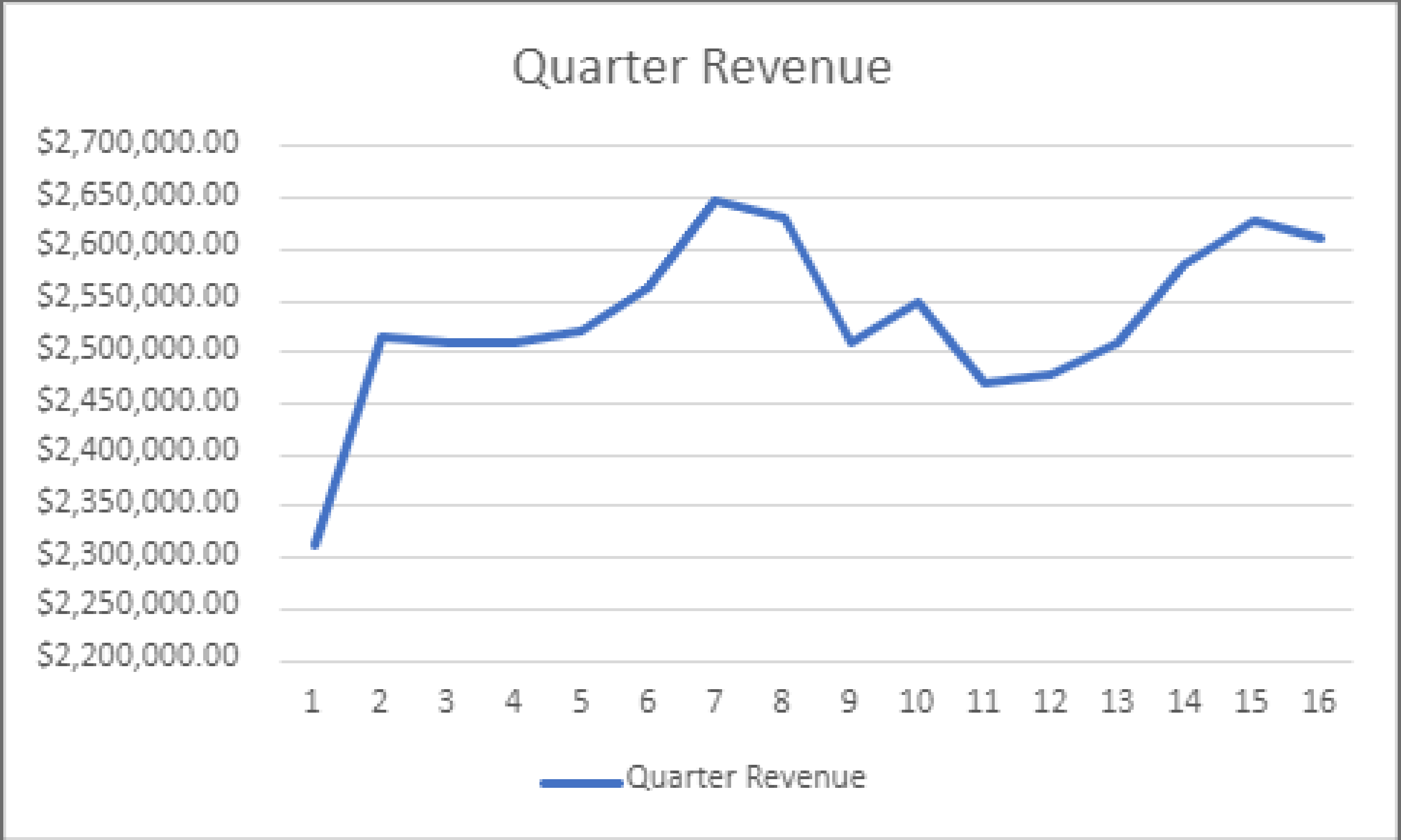


Linear Program Optimization

The concept of switching cells as production changes increases efficiency of production decreasing waste.



Linear Program



Risks - An Overview

- Full grid reliance
- Renewable energy
- Purchase raw materials
- Finance
- Self-obtain raw materials
- Transportation
- Infrastructure style
- Design

Conclusion - Key Takeaways

- Steel MPS designs are profitable (P&L, Monte-Carlo)
  - Cash flow positive 5-8 quarters after deployment
  - $300-$800k profit/quarter at least (after breakeven)
- MPS potential to optimize product types/processes to changing demand and remain profitable (linear program)
- Difficult to quantify risks without industry data, but should be included in decision-making

Conclusion - Student Findings

- **Our model outputs are only as good as the data provided**
  - Difficulty predicting true costs/expenses
  - Difference between manufacturer preferences and optimal solution(s)
  - Greatest uncertainties: machine maintenance, operations, financing
- **We (mostly) achieved the objectives we set as a team**
  - Improving understanding of MPS and how they could look in steel industry
  - Determine economic feasibility of a hypothetical MPS
  - Categorize and minimize system risks
  - Neglect truly modular technologies -> hybrid model

Recommendations

- **Consider constructing a MPS in steel industry in the near future**
  - Wait after the next recession and to capitalize on modular technologies functionalities
- **Incorporate a renewable energy source to power the facility**
  - Manufacturer will determine source/location of energy, energy type, storage plans, alternatives in case of emergency
  - Install a backup power source for reliability
  - Do not initially attempt to manage own raw material supply or transport system
- **Focus on minimizing risks of most sensitive factors**
  - Unnecessary equipment costs, machine breakdowns, extra inventory or insufficient quality

Future Project Applications

- **Expand on the profit and loss analysis**
  - Assumptions on transportation/delivery of goods, product types, difference between purchasing or self-producing raw materials,
  - Explore how to better implement taxes, workers learning curve, module capacity and utilization impact profitability
- **Conduct additional research or tests to estimate mechanics of a steel MPS**
  - System HVAC, labor automation, energy storage, power source connection
- **Alternative forecasting techniques**
  - EOQ to minimize inventory, holding, order costs
  - Requires understanding of demand expectations, supplier options and rates
- **Other**
  - Measuring emissions
  - Finance vs leasing
  - Ergonomics
  - Robust business plan
  - Levelization equation (concept of storage)

Thank You!

Sponsor: Robert Freda (GenH)

Advisor: Professor Sara Saberi (WPI)

Please see our report for the bibliography of our sources.

SUPPLEMENTARY SLIDES AFTER THIS SLIDE

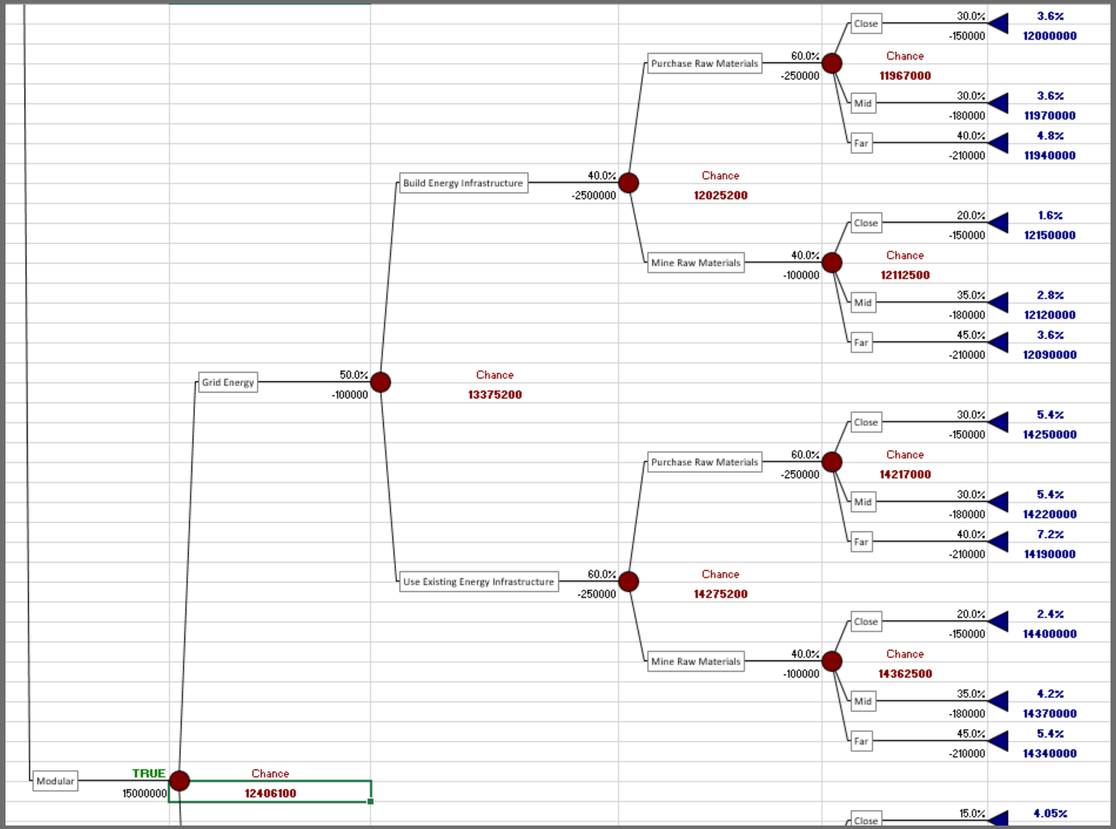
Assumptions

1. The factory, not including the machinery or equipment, will not use more than 5.5 kWh of energy per hour.
2. The factory will operate for 16 hours a day, 7 days per week.
3. There will be a constant energy supply, either powered by the grid or a reliable renewable energy source. In all likelihood, this might not necessarily be accurate.
4. Each module fits the designed cells. They fit inside shipping containers, which average widths of under 9 feet.
5. Cells can be adjusted as necessary, although there is a cost associated with adding or removing.
6. Demand is expressed as total steel required, but it is separated into production ratios per product type.
7. Each product is manufactured in its own respective cell type.
8. Machines and equipment will be financed or leased instead of purchased in quarter 1.
9. Total production and equipment costs will increase by a variable percentage each period or quarter.
10. Raw materials are purchased as needed, though we are not considering the cost to import materials.
11. The cost of business is stagnant between quarters.
12. There will be a constant demand growth for each product in the regular P&L. In the linear programming and Monte-Carlo simulations, the growth rate will change depending on outside economic factors. The production ratios and selling prices will also adjust.
13. There is a learning curve associated with each product.
14. Each product is designed for manufacture.
15. Handling time is ignored since it does not add value to the product.
16. Machines are financed by a constant rate per quarter. In real-world applications, they likely need to make a down payment or initial investment with quarterly payments.

Risks - The Details

- **Full grid reliance**
  - electricity rates
  - outages
  - emissions
- **Renewable energy**
  - portion of power required
  - not always available
  - storage
  - influence of climate, geography, terrain, location
- **Purchase raw materials**
  - paying at least the mark-up price, shipping, handling
  - extra supply chain level
  - lack of control
  - longer lead times
- **Self-obtain raw materials**
  - control over pricing
  - reduces level of supply chain
  - limited to raw material available
- **Transportation**
  - who transports raw materials to site of manu?
  - Send finished goods to customer?
  - each option has economic, control, time implications
- **Infrastructure style**
  - existing of build new
  - conjunction to renewable energy and power source connection
- **Design**
  - significant heat buildup
  - disconnect between modules, breakdowns
  - emissions implications due to technology
- **Finance**
  - recession impacts on supply and demand
  - finance vs lease vs purchase

Decision Tree



Decisions:

- Type of facility: modular, hybrid, traditional
- Energy type: grid, non-grid
- Energy infrastructure: Current or new
- Raw materials: purchase or mine
- Customer target distance: close, mid or far

Largest payout: modular -> grid energy -> use existing energy infra. -> mine -? close [$14.4 million]

Likeliest outcome: modular -> non-grid -> build -> purchase -> far

[$11 million]

Monte Carlo: List of Assumptions (pt.1)

1. 5,000 iterations of a scenario is a large enough sample size. All probabilities will be from 5,000 iterations of a simulation
2. All workers are paid a constant rate of $30/hour, and there are two shifts of workers per work day.
3. The facility is functioning on weekends, but not on Federal holidays, meaning it is open 340 work days in a year.
4. The MPS requires a two-quarter organization and start-up period in order to locate an adequate facility, hire the required workers, and obtain equipment.
5. The labor hours associated with establishing the MPS before the first production quarter is calculated from 15 workers working 12 weeks per quarter, for $35/hour and the sum is added to the cost of production in Table Q.
6. The cost of equipment is the cost of financing the machines at a financing rate of 3% and an expected price increase rate of 1% per quarter.
7. There is a production manufacturing overhead mark-up percentage on the production cost for ‘hidden fees’ in production, whether it is value-non-added time, increased defects, etc. It is represented as a probability distribution of a percentage and is multiplied by the sum of production costs (Table H) to get the ‘true’ sum of production costs.
8. There is a facility manufacturing overhead markup percentage for ‘hidden’ facility costs (like Table C) that are not accounted for in the cost of production for a given product. This markup does not impact any cost calculations since this would be double-counting, it only impacts the selling price of a product (Table I).
9. The growth rate in product production quantities (Table I) used to calculate the revenue and production costs for each quarter is the same for all products and it follows ¼ the annual growth rate indicated in Table A.

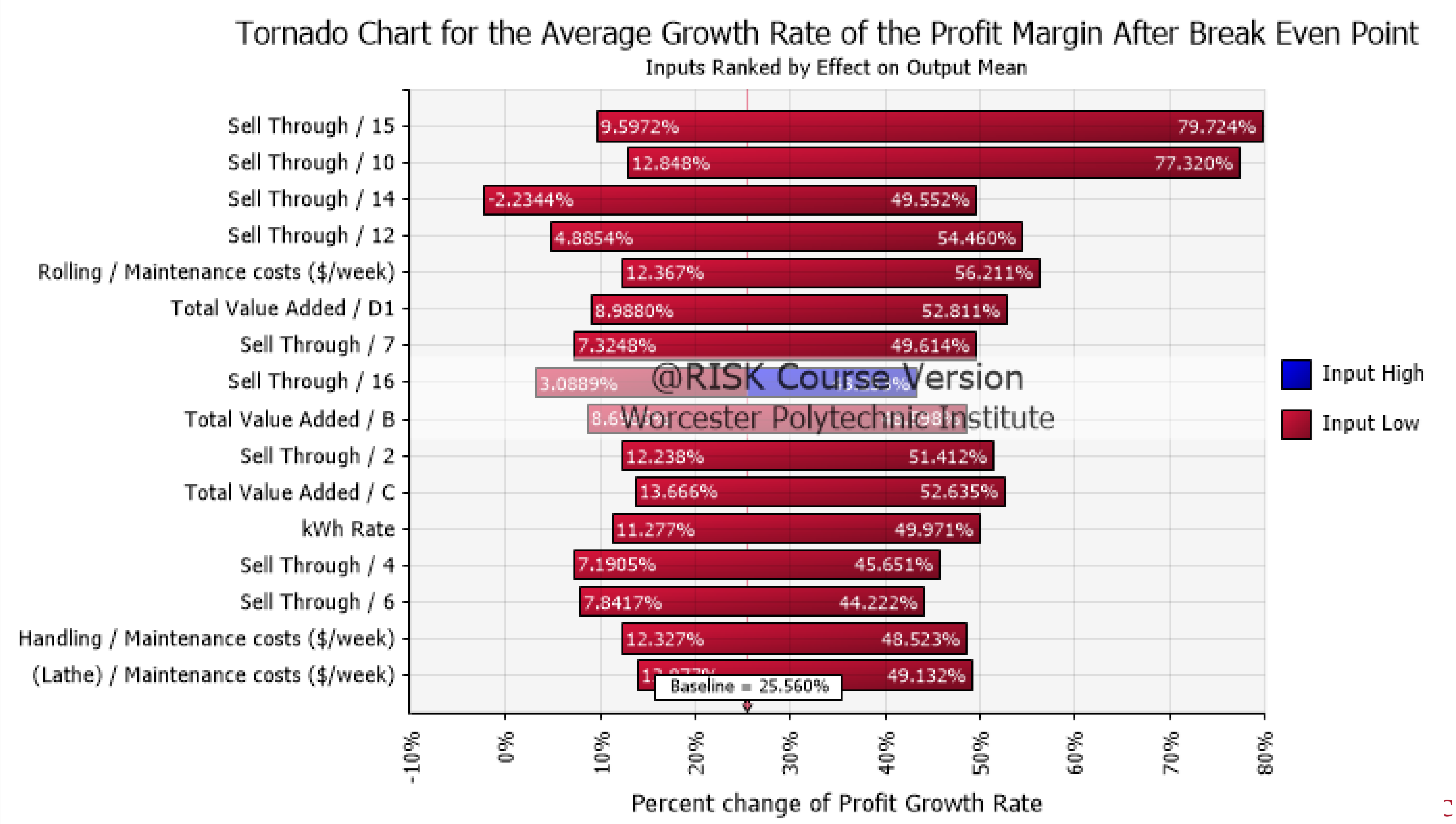
Monte Carlo: List of Assumptions (pt.2)

10. The following statistics are representative measures of the economic success of a manufacturing system and therefore will be used as output statistics of the model. 1. Quarter in which the MPS breaks even 2. Cash Flow four quarters after breaking even 3. Average growth rate after the break even point 4. Return on investment (ROI) four quarters after the break even point
11. The @Risk Simulation will use a random number generator (Mersenne Twister) and the sampling type is “Monte Carlo”, meaning the numbers are randomly generated and the variable’s value is determined from where the random number falls on a cumulative probability distribution. This sampling technique for Monte Carlo generally results in random numbers that are not forced to converge to a set distribution.
12. Defective units are scrapped and the materials are recycled. The potential money ‘saved’ from recycling a unit is not calculated. The scrapping cost represents the cost of time, movement, or other resources in order to ‘scrap’ that unit. (Table H)
13. Quality control costs are the costs associated with the time required to check the units and conduct the required tests. (Table H)
14. The possible revenue (assuming 100% sell through rate) and the cost of production (Table K and Table L, respectively) use an equation for continuous compounding ($P(t) = P0er{\cdot}t$) where $P0$ is the calculated value for that quarter and each quarter is calculated independently.
15. The sell-through rate is the ratio that product is sold at full price, and various discounted prices. We used one sell-through rate for the proportion of goods sold at full price, and then assumed the remaining goods were sold at half of the selling price.
16. Each simulation is run on a 16 quarter production period with a two-quarter start up period. The quarters are labeled according to production, so quarter 1 is the quarter where production is first started.

Monte Carlo: Analysis of Characteristics

MPS Characteristic	Effect of Characteristic on MPS Manufacturing	Economic Effect / Trend
Design for manufacture (DFM) and medium to low volume production	Lower defect rate, higher quality goods	More cost-effective and higher profits; good customer retention rates → higher sell-through
Versatile machine set	Quick and cheap production switching between products	Higher sell-through rate, quick market response/competitive market
Versatile machine utilities in cells and product switching	Less overproduction	Lower inventory costs and lower proportion of discounted selling price (higher sell-through; higher average profit per unit)
Modular, transportable manufacturing design in a non-permanent location	Lower initial investment for establishing the facility	Higher return on investment (ROI)
Standardized MPS design for deploying a facility (in an existing facility)	Quick start-up time	Higher return on investment (ROI)
Versatile machine utilities in cells and product switching	Lower product investment cost, lower risk pursuing a product	Higher profits or lower loss on products with a short success-lifespan or that flop
Versatile machine utilities in cells and flexible production process	Quick, low cost adjustments to product design and production	Higher market retention on high rates of product design changes and innovation
Design for manufacture (DFM) and medium to low volume production	Lower product investment cost and flexible product configurations	Targeting an underserved market for medium to low demand semi-specialized goods

Monte Carlo


Tornado Chart for the Average Growth Rate of the Profit Margin After Break Even Point
Inputs Ranked by Effect on Output Mean
Sell Through / 15
Sell Through / 10
Sell Through / 14
Sell Through / 12
Rolling / Maintenance costs ($/week)
Total Value Added / D1
Sell Through / 7
Sell Through / 16
Total Value Added / B
Sell Through / 2
Total Value Added / C
kWh Rate
Sell Through / 4
Sell Through / 6
Handling / Maintenance costs ($/week)
(Lathe) / Maintenance costs ($/week)
9.5972%
79.724%
12.848%
77.320%
-2.2344%
49.552%
4.8854%
54.460%
12.367%
56.211%
8.9880%
52.811%
7.3248%
49.614%
3.0889%
12.238%
51.412%
13.666%
52.635%
11.277%
49.971%
7.1905%
45.651%
7.8417%
44.222%
12.327%
48.523%
49.132%
Baseline = 25.560%
@RISK Course Version
Worcester Polytechnic Institute
Input High
Input Low
-10%
0%
10%
20%
30%
40%
50%
60%
70%
80%
Percent change of Profit Growth Rate

OUTLINE FOR THE TEAM - AGENDA

1. Our Assumptions for the MPS (Quick summary/recap)
2. Our Goal and Objectives (Quick summary/recap)
3. Design assumptions (Quick summary/recap)
   a. Cell layout/switching
   b. Outline modular characteristics
   c. Modularization drivers
4. Economic Analysis
   a. Goal objectives: ROI and Margin (Table Q)
   b. Parameters that go into the objectives (Table Q)
   c. Tables that go into Table Q
   d. Data and inputs into the model
   e. Outcome of P&L analysis
5. Monte Carlo
   a. Outcomes with uncertainty (Table R)
   b. Variables/distributions that are different from P&L
   c. Sensitivities and trends
6. Linear Program
   a. Set, Parameters, Decision Variables, Objective Function
   b. Outcome into P&L
7. Bottom line outcome, observations, takeaways
   a. Concrete outline of how to our deliverables are useful for him and what he needs
8. Suggestions for future projects

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