Model Based Enterprise: Costs and Benefits for Discrete Manufacturing

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Outline

- Overview of Economics and MBE
  - Cost Modeling
  - Economic Decision Making
- MBE Related Manufacturing Costs/Losses
- Economic Tools
  - Manufacturing Cost Guide
  - Monte Carlo Tool
- Economic Standards and Guides
- Summary

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Costs and Cost Modeling

- Cost Modeling
  - Industry level research
  - Estimate various production costs
  - Costs/impacts that
    - Persist over time
    - Persist across products
  - Production activities with high costs and environmental impacts
- Economic Decision Making
  - Methods/standards for investment analysis
  - Produce tools for examining or estimating costs

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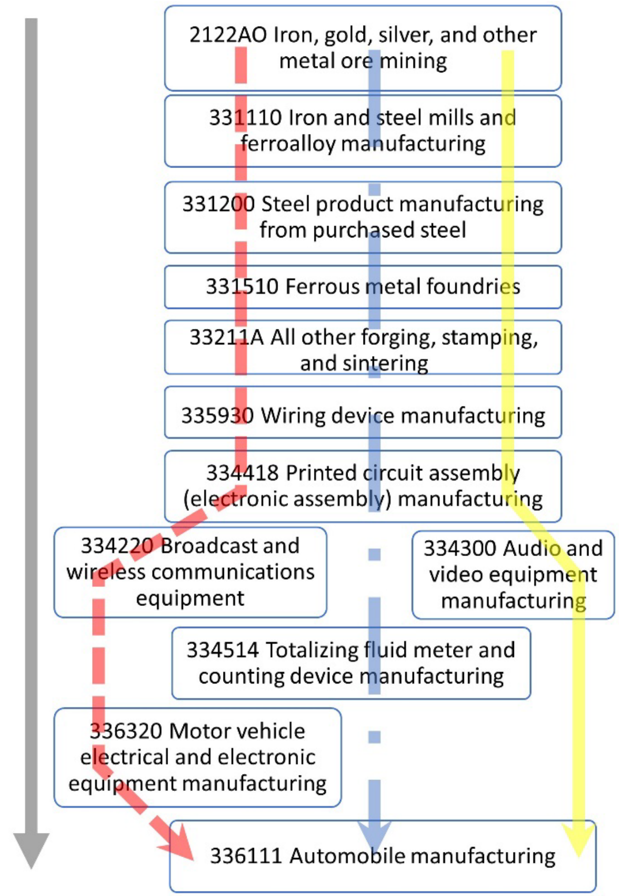
Cost Modeling: Supply Chain Research

- Natural Hazards
  - Impact manufacturers more
  - Largest impact → supply chain
- Domestic Localization
  - For some tier-1 suppliers increases productivity/production
- Resource Consumption
  - 80% of problem due to 20% of the cause
  - Some supplies account for large impact and cost
- Flow Time
- Maintenance costs
  - Reactive to Predictive



Supply-chain Map for the Longest Three Routes for Automobiles/Truck Manufacturing

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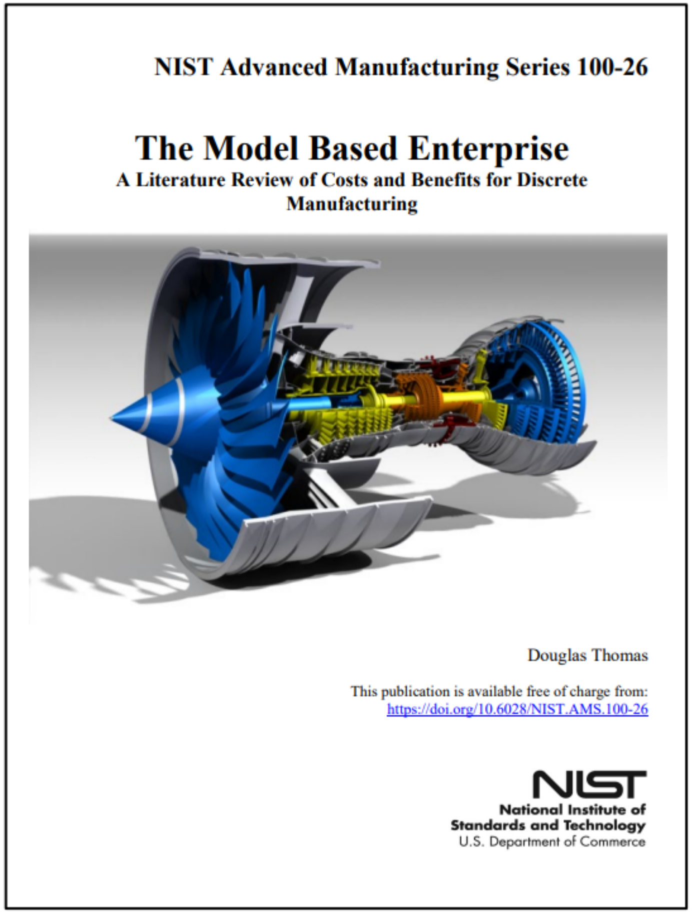
Inadequate Design and Modeling Information/Data

- Examination of literature and existing data
- Economics
    - Costs/Benefits
- Product models (e.g., CAD/CAM)
- Simulation models of manufacturing processes
- Interoperability between software platforms


NIST Advanced Manufacturing Series 100-26

The Model Based Enterprise
A Literature Review of Costs and Benefits for Discrete Manufacturing

Douglas Thomas

This publication is available free of charge from:
https://doi.org/10.6028/NIST.AMS.100-26

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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Case Studies and Narratives

- Boeing 787 Dreamliner
  - Moved to modular design
    - Parts from all over the world
  - Design problems → parts didn't fit together
  - Boeing had to send engineers to suppliers throughout the supply chain
  - Purchased some suppliers
  - One cause was the failure to clearly communicate requirements and data to suppliers

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Case Studies and Narratives

- DoD ground vehicles
  - Production development went from 2 years to 90 days
- Construction equip. manufacturer
  - Product development went from 27 months to 9 months
- Proctor and Gamble
  - Savings due to MBE exceeded $1 billion

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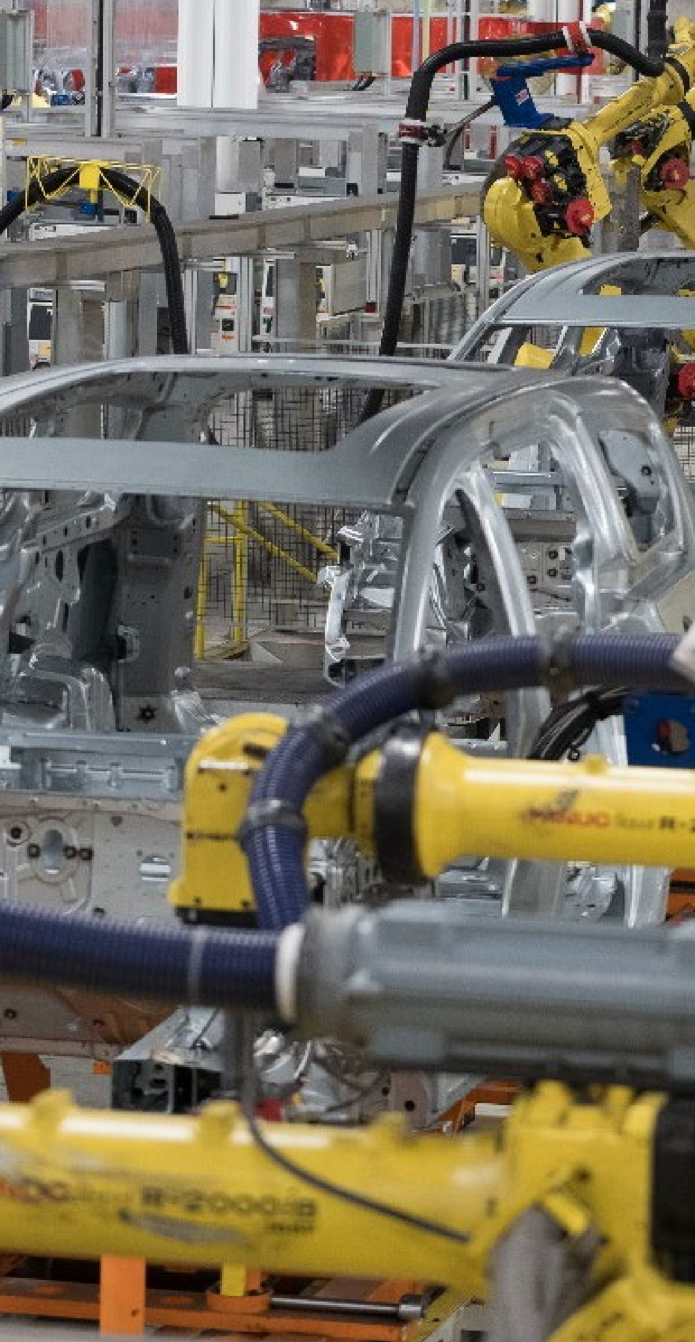

Chrysler: Robotic welding stations at Windsor Fiat Chrysler Assembly Plant.

General Efficiency Losses (preliminary estimates)

- In factory (discrete manufacturing)
    - Percent of planned production time that is downtime
        - Average: 7.8 %
        - Median: 5.0 %
    - Product defect rate
        - Average: 1.22 %
        - Median: 0.02 %
- In factory MBE related is some portion of these

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Labor Hours Spent Making Clarifications and Answering Questions

Occupation	Activity	Hours per Week	Mean Hourly Wage	Total US Employment	Potential Loss ($Billion)
Engineers	Answering questions or clarifying drawings	6.4	$44.62*	303 440*	8.40
	Creating additional drawing documentation	5.5			
Machinists	Answering questions or clarifying documentation	4.7	$21.75	384 350	3.84
	Generating additional documentation	4.1			
* Mechanical engineers					

Sources: Lifecycle Insights. "Average Time Spent Authoring, Clarifying and Amending Documentation." The 2014 State of Model Based Enterprise Report. https://www.lifecycleinsights.com/finding/average-time-spent-authoring-clarifying-and-amending-documentation/
Bureau of Labor Statistics. "Occupational Employment Statistics." https://www.bls.gov/oes/current/oes_nat.htm

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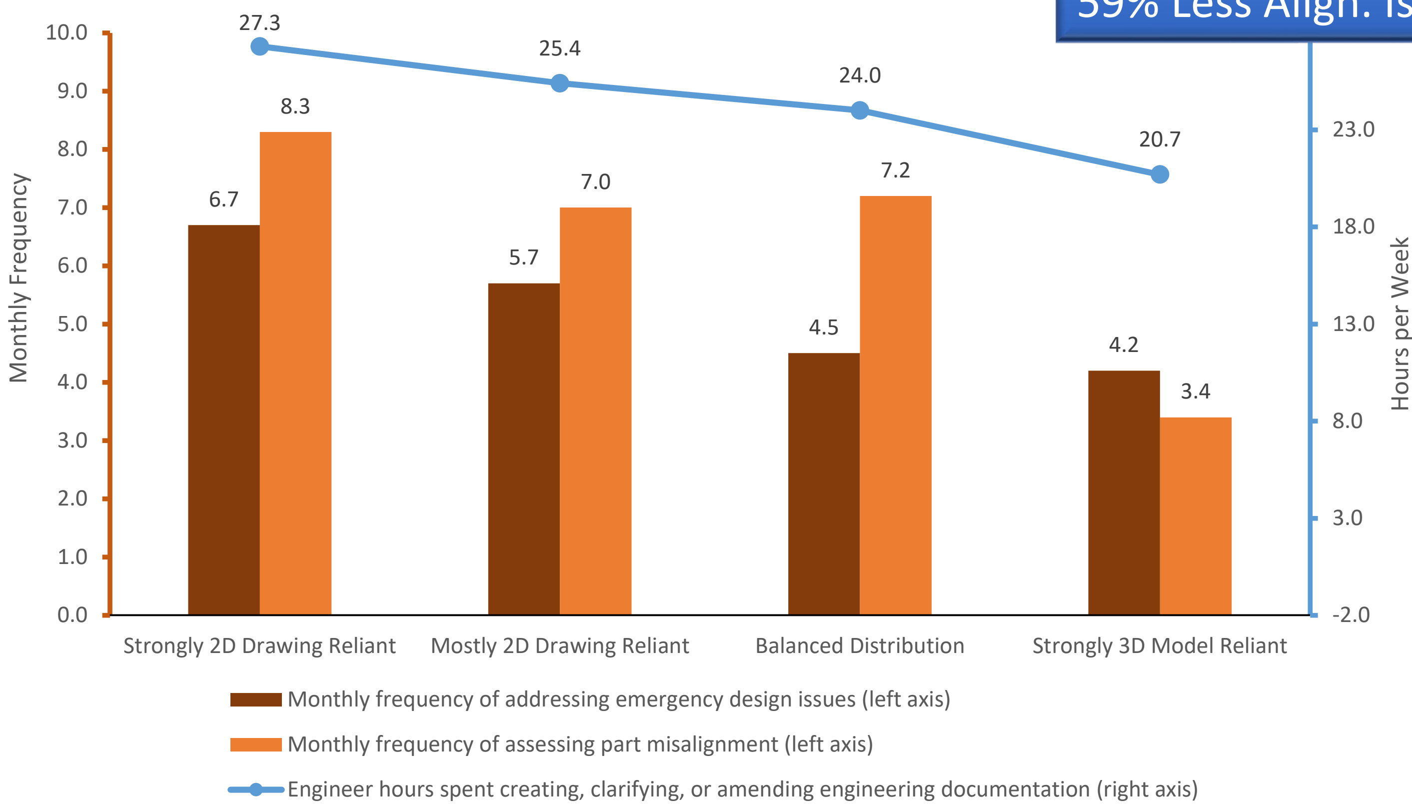
Frequency of Design Issues by 2D/3D Drawing Reliance

24% Less Hours
37% Less Design Issues
59% Less Align. Issues



Source: Lifecycle Insights. "Quantifying the Value of Model Based Definitions: Saving Time, Avoiding Disruptions, Eliminating Scrap." Presentation. https://www.lifecycleinsights.com/wp-content/uploads/2018/04/LCI-MBD.pdf

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3D Model Adoption and Use, Percent of Respondents (i.e., organizations)

No 3D Models
Heavy 3D Model User

What percent of your designs have been released with PMI-embedded 3D models

What percent of your designs have been released with 2D drawings	None (0%)	Little (1%-25%)	Some (26%-50%)	Majority (51%-75)	Most (76%-99%)	All (100%)	TOTAL
None (0%)	0.4	0.4	-	-	1.3	0.4	2.5
Little (1%-25%)	2.5	1.7	0.8	1.3	2.5	1.3	10.1
Some (26%-50%)	1.3	2.9	1.3	2.1	-	-	7.6
Majority (51%-75)	2.5	4.2	3.8	0.8	-	-	11.3
Most (76%-99%)	11.8	9.2	2.9	2.5	2.9	0.8	30.1
All (100%)	24.4	5.5	0.8	2.5	2.1	2.9	38.2
TOTAL	42.9	23.9	9.6	9.2	8.8	5.4	99.8
TOTAL (Excl. Grey)*	41.5	21.6	10.1	10.5	10.1	6.2	100.0

* This percentage is recalculated excluding those areas greyed out. The greyed areas are excluded as they represent designs that are neither 2D or 3D.
Note: Areas are greyed out due to designs that have neither 2D or 3D drawings. That is, the sum of 2D drawings and 3D drawings do not approximate 100 % of designs.
Source: Lifecycle Insights. Quantifying the Value of Model Based Definitions: Saving Time, Avoiding Disruptions, Eliminating Scrap. https://www.lifecycleinsights.com/wp-content/uploads/2018/04/LCI-MBD.pdf

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Costs due to Interoperability Issues, 2016 ($billion)

NAICS Code	NAICS Description	Cost Avoidance (low estimate)	Cost Avoidance (high estimate)
333	Machinery manufacturing	4.3	8.7
334	Computer and electronic product manufacturing	3.6	7.3
335	Electrical equipment, appliance, and components	1.5	3.1
336	Transportation equipment manufacturing	11.6	23.7
	Total	20.9	42.9

Data Sources: Leonard, Scott and Mel Hafer. Advanced Manufacturing Enterprise: Strategic Baseline. https://www.dodmantech.com/JDMTP/Files/AME_Strategic_Baseline_03_Nov_11.pdf
Census Bureau. Annual Survey of Manufactures. https://www.census.gov/programs-surveys/asm.html

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Chrysler 200 Factory, Sterling Heights Assembly Plant

Application

- Combined with surveys and other public data
  - Energy
  - Disaster impact
  - Cyberattacks
  - Maintenance
  - Waste (e.g., scrap and defects)
- Free software tool for practitioners and applied researchers
  - Measure and compare manufacturing costs/losses
  - Potential distribution: MEP

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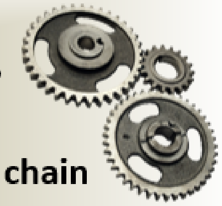
The Manufacturing Cost Guide



A Tool for estimating costs in the US manufacturing industry and it's supply chain

Because data speaks louder than words.

Welcome to **The Cost Guide**.

Congratulations on starting your journey to join those with elite manufacturing industry knowledge. No longer will your beliefs about industry be based on anecdotal and nonscientific evidence, but will rather be grounded in data built on a foundation of mathematical, statistical, and empirical evidence. This tool uses a combination of data sources and analysis methods to analyze the US manufacturing industry and its supply chains. Enjoy your data adventure!

Lets Get Started

Photo Credit: The Chrysler 200 Factory Tour, an interactive online experience using Google Maps Business View technology, takes consumers inside the new 5-million-square-foot Sterling Heights Assembly Plant for a behind-the-scenes peek at how the 2015 Chrysler 200 is built. http://media.fcanorthamerica.com/homepage.do?mid=1

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Select the output or metrics

Select the output or metrics to be used for the examination.

For Supply Chain Analysis

- [ ] **Value Added**: Value added is considered the primary measure of economic activity. This data provides the value added required to produce commodities for intermediate use (i.e., supplies to other industries) and final demand
- [ ] **Environmental Impact**: This analysis provides an estimate of the environmental impact associated with producing intermediate use (i.e., supplies to other industries) and final demand
- [ ] **Identify Industries with High Value Added + Environmental Impact**: This analysis combines the value added analysis and the environmental impact analysis to identify those industries in the supply chain that have a disproportionally high level in both areas
- [x] **Analysis of Energy use**: This analysis estimates the value of energy used throughout the supply chain to produce intermediate use (i.e., supplies to other industries) and final demand. It further details how the energy was used.
- [ ] **Analysis of Labor Compensation by Occupation**: This analysis provides the different types of labor needed from different industries to produce commodities for intermediate use (i.e., supplies to other industries) and final demand
- [ ] **Purchases by Industries**: This table provides the use of commodities by industries. It is the Use table of an input-output model
- [ ] **Assets (i.e., capital) Used**: This table estimates the value of capital needed to produce intermediate use (i.e., supplies to other industries) and final demand

Back to Start | Guidance and Help | Submit

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Select the commodities to be examined.

Select commodities by Group

- [ ] Select/Deselect all (**this selection takes a moment**)
- [ ] Food, Beverage, and Tabacco Products (NAICS 311-312)
- [ ] Discrete Products (NAICS 313-323, 327-332, 337-339)
- [ ] Discrete Tech Products (NAICS 333-336)
- [ ] Process Products (NAICS 324-326)

NAICS Classification

Back to Start

Submit

Select commodities individually

[x]	3363A0	Motor vehicle steering, suspension component (except spring), and brake systems manufacturing
[ ]	336411	Aircraft manufacturing
[ ]	336412	Aircraft engine and engine parts manufacturing
[ ]	336413	Other aircraft parts and auxiliary equipment manufacturing
[ ]	336414	Guided missile and space vehicle manufacturing
[ ]	33641A	Propulsion units and parts for space vehicles and guided missiles
[ ]	336500	Railroad rolling stock manufacturing
[ ]	336611	Ship building and repairing
[ ]	336612	Boat building
[ ]	336991	Motorcycle, bicycle, and parts manufacturing
[ ]	336992	Military armored vehicle, tank, and tank component manufacturing
[ ]	336999	All other transportation equipment manufacturing
[ ]	337110	Wood kitchen cabinet and countertop manufacturing
[ ]	337121	Upholstered household furniture manufacturing

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Results: Manufacturing Energy Consumption by End Use ($million)

This tab presents the energy needed from each industry to produce the selected commodities. The energy cost is broken into subcategories of what the energy was used for.

Energy Use Definitions

NAICS Classification

		Boiler Fuel	Non-Process Use				
NAICS Code	Industry Description	Indirect Uses-Boiler Fuel	Facility Lighting	Facility HVAC	Conventional Electricity Generation	Other Facility Support	Other Nonprocess Use
3363A0	Motor vehicle steering, suspension component (except spring), and brake systems manufacturing	7.975	22.157	46.651	0.000	7.521	2.332
331110	Iron and Steel Mills and Ferroalloy Manufacturing	10.057	3.962	10.177	0.000	1.786	0.312
331200	Steel Product Manufacturing from Purchased Steel	0.423	0.399	0.755	0.000	0.131	0.024
331310	Alumina and Aluminum Production and Processing	1.053	0.963	1.836	0.000	0.320	0.059
331410	Nonferrous Metal (except Aluminum) Smelting and Refining	0.442	0.626	1.081	0.000	0.188	0.036
331420	Copper Rolling, Drawing, Extruding, and Alloying	0.195	0.184	0.348	0.000	0.061	0.011
331490	Nonferrous Metal (except Copper and Aluminum) Rolling, Drawing, Extruding, and Alloying	0.470	0.250	0.567	0.000	0.099	0.018

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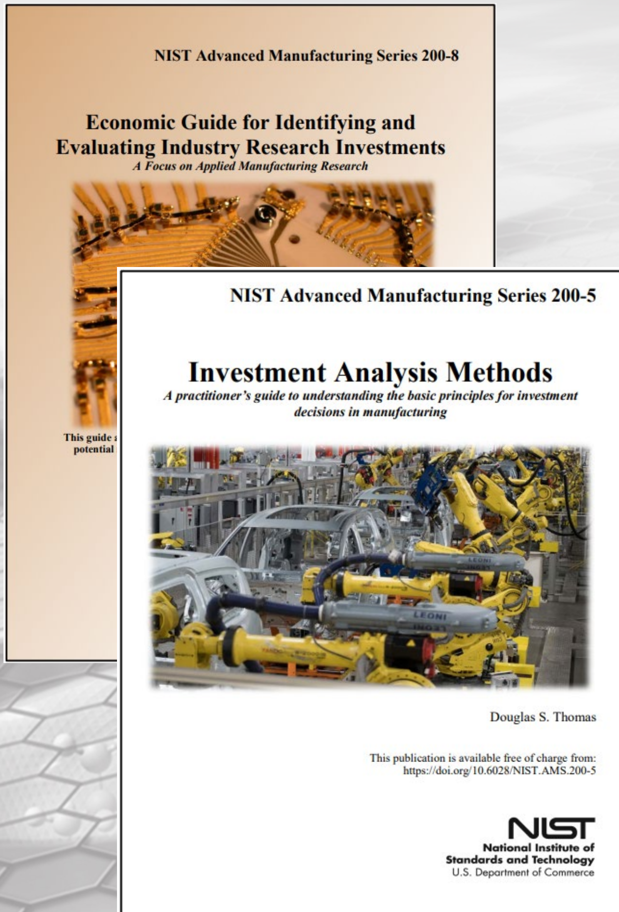
Using Data: Guides, Standards, and Other Tools



- ASTM Standard for Sustainable Investment Analysis (forthcoming)
  - Combines LCA and economic decision making
- Guide to Investment Analysis
- Guide for identifying industry research investments (public research efforts)
- Monte Carlo Tool

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Chrysler: Robotic welding stations at Windsor Fiat Chrysler Assembly Plant.

Monte Carlo Tool

- Free Excel tool
- Uncertainty analysis
- Monte Carlo Analysis
  - Simulation
  - Samples from user defined distributions
    - Triangular
    - Normal
    - Uniform
    - Lognormal
  - User defined number of simulations

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Monte Carlo Tool

Monte Carlo Analysis Made Simple

Version 1.0

Welcome to **The Monte Carlo Tool**.

This tool provides an easy way to implement Monte Carlo analysis following the simulation segment of ASTM E1369. The user can enter equations and models where variables within the model are drawn from random sampling. What is Monte Carlo Analysis?

Let's Get Started

Disclaimer

Photo Credit: The Chrysler 200 Factory Tour, an interactive online experience using Google Maps Business View technology, takes consumers inside the new 5-million-square-foot Sterling Heights Assembly Plant for a behind-the-scenes peek at how the 2015 Chrysler 200 is built. http://media.fcanorthamerica.com/homep

Instructions

Step 1: Navigate to the "User Calculations" tab or add a new tab by clicking the "+" symbol next to the tabs below.

Step 2: Enter the desired model and/or calculations. For instance, if the user is examining costs, then they would enter the price and quantity calculations. The equations to the right can be used for creating randomly sampled variables within these calculations. Show Me

Step 3: Navigate to the "Forecasts" tab.

Step 4: Enter the number of desired trials.

Step 5: Enter the variables to be forecasted sequentially in columns "B" and "C" by entering "=" and selecting the cells with the forecasted variable. Use column "C" to provide a name of the forecasted variable. Show Me

Step 6: Click the "Start Simulation" button in the "Forecasts" tab. The results will be shown in a tab labeled "MC Data." The user can use this data to calculate summary statistics, such as the average, maximum, and minimum values.

Triangular Distrubution:	**Equation**	=RandomTriangular(low, mode, high)
	Variables	**low** is the minimum, **high** is the maximum **mode** is the most likely value
Normal Distribution:	**Equation**	=RandomNorm(mean,stdev)
	Variables	**mean** is the mean **stdev** is the standard deviation
Lognormal Distribution:	**Equation**	=RandomLognorm(mean,stdev)
	Variables	**mean** is the mean **stdev** is the standard deviation
Discrete Uniform:	**Equation**	=RandBetween(bottom,top) **bottom** is the lowest value **top** is the highest value
Uniform:	**Equation**	=RandomUniform(low,high) **low** is the minimum value **high** is the maximum
Yes/No	**Equation**	=yes(prob) **prob** is a value between 0 and 1, representing the probability of a yes, where yes equals 1 and no equals 0
Poisson Distribution:	**Equation**	=RandomPoisson(mean) **mean** is the mean

Trials and Forecasts

Start Simulation

Clear Results

Simulation Progress
0

	User Selected Total
Trials	10000

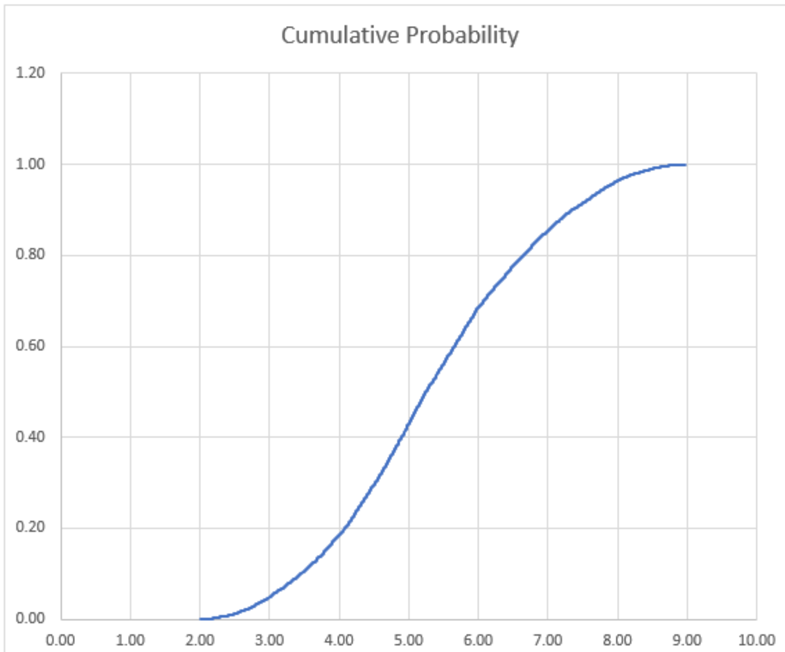
ID	Simulated Forecast Values	Name
1	5.568749682	Per unit cost

In this tab, the user selects the number of trials and indicates what is to be forecasted. Typically, 1000 or more trials are selected. The variables to be forecasted must be entered sequentially (Do not leave blank cells in between) in columns "B" and "C" to the left, starting with cells B12 and C12. For instance, if the user types 'User Calculations'!E11 into cell B12, then the value in cell E11 in the "User Calculations" tab will be forecasted. A maximum of 1,000 forecast variables can be entered.

Once the user has entered the forecast variables, the simulation can be started by clicking the "Start Simulation" button.

The simulation results will be revealed in a tab titled "MC Data."

	Per uni	prob
1	2.02	0.00
2	2.02	0.00
3	2.04	0.00
4	2.05	0.00
5	2.05	0.00
6	2.10	0.00
7	2.13	0.00
8	2.13	0.00
9	2.13	0.00
10	2.14	0.00
11	2.16	0.00
12	2.17	0.00
13	2.17	0.00
14	2.18	0.00
15	2.18	0.00
16	2.18	0.00
17	2.19	0.00
18	2.19	0.00
19	2.20	0.00
20	2.20	0.00
21	2.21	0.00
22	2.21	0.00
23	2.22	0.00
24	2.22	0.00
25	2.23	0.00
26	2.23	0.00
27	2.23	0.00
28	2.23	0.00
29	2.24	0.00
30	2.24	0.00
31	2.24	0.00
32	2.24	0.00
33	2.25	0.00
34	2.25	0.00
35	2.26	0.00
36	2.26	0.00
37	2.26	0.00



Use the output to create a cumulative probability graph or other analysis

Summary of Economics Related to MBE

- Avg. Unplanned Downtime: 7.8%
- Avg. Defect rate: 1.22 %
- $12.2 billion clarifying drawings
- $20.9-$42.9 billion on data issues
- 3D drawings
  - Reduce hours on clarifications (24%)
  - Reduce part misalignment (59%)
  - Reduce design issues (37%)
  - However, only 23% use 3D drawings for most parts

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Summary: Costs and Cost Modeling

- Other costs
  - Natural Hazards
  - Flow time
  - Resource consumption
  - Localization
- Guides and Standards
  - Economic analysis
  - Simulation
  - Estimating costs

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Summary: Costs and Cost Modeling

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