Reliability & Risk Division
ASQ Excellence Through Quality™

Quality and reliability tools for: capacity planning and costing

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RELIABILITY MAINTENANCE & MANAGING RISK CONFERENCE

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November is one of the best months in Minnesota

New

?

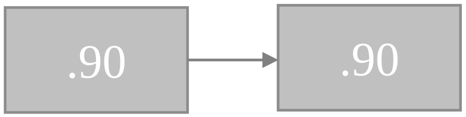
Imagine that our company is outsourcing our new skid shoe

- Knowns:
  - High volume for this new skid shoe
    - 1 million per year (not shared during supplier selection)
  - We want and have found a capable local supplier
  - Supplier proposes machining the skid shoes

- Questions for the supplier:
  - Q1: How many steps are in the process flow?
  - A1: 6
  - Q2: What is the annual capacity for one manufacturing line?
  - A2: 1.2 million per year

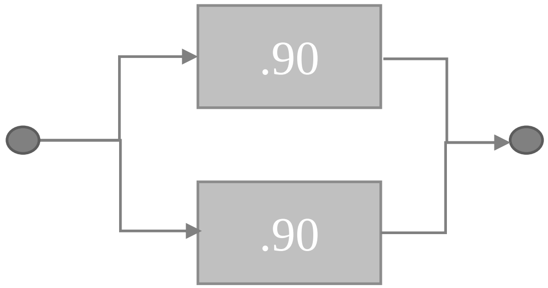
Key concept review from reliability engineering

For components in series and assumed to be independent, it is shown like this:



And the probability that the network functions is: P = R(A) * R(B), or .9 * .9=.81

For components in parallel, they look like this and have slightly different math.



The probability that the network functions is: P = 1-(1-R1) * (1-R2).
Or P= 1-(1-.9)*(1-.9)= 1-.01=.99

Can we use this logic to build a better capacity planning process?

Overall Equipment Effectiveness is a common term

- The math is A*P*Q
- A is availability
- P is performance
- Q is quality

- Today, I will focus on Availability
- Define a new term as Cell Availability
- Discuss a methodology to assist in modeling it based on lessons learned from COVID-19

Cell availability combines machine and operator together

			P (A*B)	A	B	Machine		Operator	
Process Step	**Machine ID**	**Operator ID**	**Overall Equipment**	**Machine**	**Operator**	**Total Days/Year**	**Days Machine was available last year**	**Days Scheduled to Work**	**Complete Days Worked**
1	CNC Mill 1	Operator 23							
2	Deburr Station 1	Operator 19							
3	Electropolish Line 1	Operator 7							
4	CMM 1	Operator 56							
5	Comparator 2	Operator 18							
6	Micrometer 23	Operator 67							
	Process Performance %								

- Traditional Availability is machine level only
- Today, we will add Operator to that concept and call the new term:
  - cell availability
  - That is shown in the column labeled Overall Equipment
- Why?: Each day, we need the machine AND the operator available.
- In probability terms this equates to P(A AND B)= P(A)*P(B) (independence)

Fill in the template with historical data and run calculations

					Machine		Operator	
Machine ID	**Operator ID**	**Overall Equipment**	**Machine**	**Operator**	**Total Days/Year**	**Days Machine was available last year**	**Days Scheduled to Work**	**Complete Days Worked**
CNC Mill 1	Operator 23	0.825	0.880	0.938	250	220	240	225
Deburr Station 1	Operator 19	0.867	0.940	0.922	250	235	245	226
Electropolish Line 1	Operator 7	0.940	0.944	0.996	250	236	245	244
CMM 1	Operator 56	0.976	0.980	0.996	250	245	245	244
Comparator 2	Operator 18	0.988	0.996	0.992	250	249	245	243
Micrometer 23	Operator 67	0.992	0.996	0.996	250	249	245	244
Process Performance %		0.643						

- Ex. CNC Mill 1, OE=.825 which is .880*.938
- Process Performance %= .825*.867…= .643 0r 64.3%
- Expected output from this line is 1.2 million (based on cell availabilities)
- Realistic average output from this line is .643*1.2 million= ~772,000
  - Which is roughly 228K short of our 1 million annual demand
- By working through this template together, assumptions can be shared, and plans can be put in place to resolve the issue, together.

First try to improve with second trained operator

							Machine		Operator 1		Operator 2	
Machine ID	**Operator ID**	**Overall Equipment**	**Machine**	**Operator**	**Operator 1**	**Operator 2**	**Total Days/ Year**	**Days Machine was available last year**	**Days Scheduled to Work**	**Complete Days Worked**	**Days Scheduled to Work**	**Complete Days Worked**
CNC Mill 1	Operator 23, 24	0.879	0.880	0.99870	0.938	0.979	250	220	240	225	240	235
Deburr Station 1	Operator 19, 20	0.936	0.940	0.99525	0.922	0.939	250	235	245	226	245	230
Electropolish Line 1	Operator 7,8	0.944	0.944	0.99998	0.996	0.996	250	236	245	244	245	244
CMM 1	Operator 56,57	0.980	0.980	0.99998	0.996	0.996	250	245	245	244	245	244
Comparator 2	Operator 18,17	0.996	0.996	0.99983	0.992	0.980	250	249	245	243	245	240
Micrometer 23	Operator 67,68	0.996	0.996	0.99992	0.996	0.980	250	249	245	244	245	240
Process Performance%		0.754										

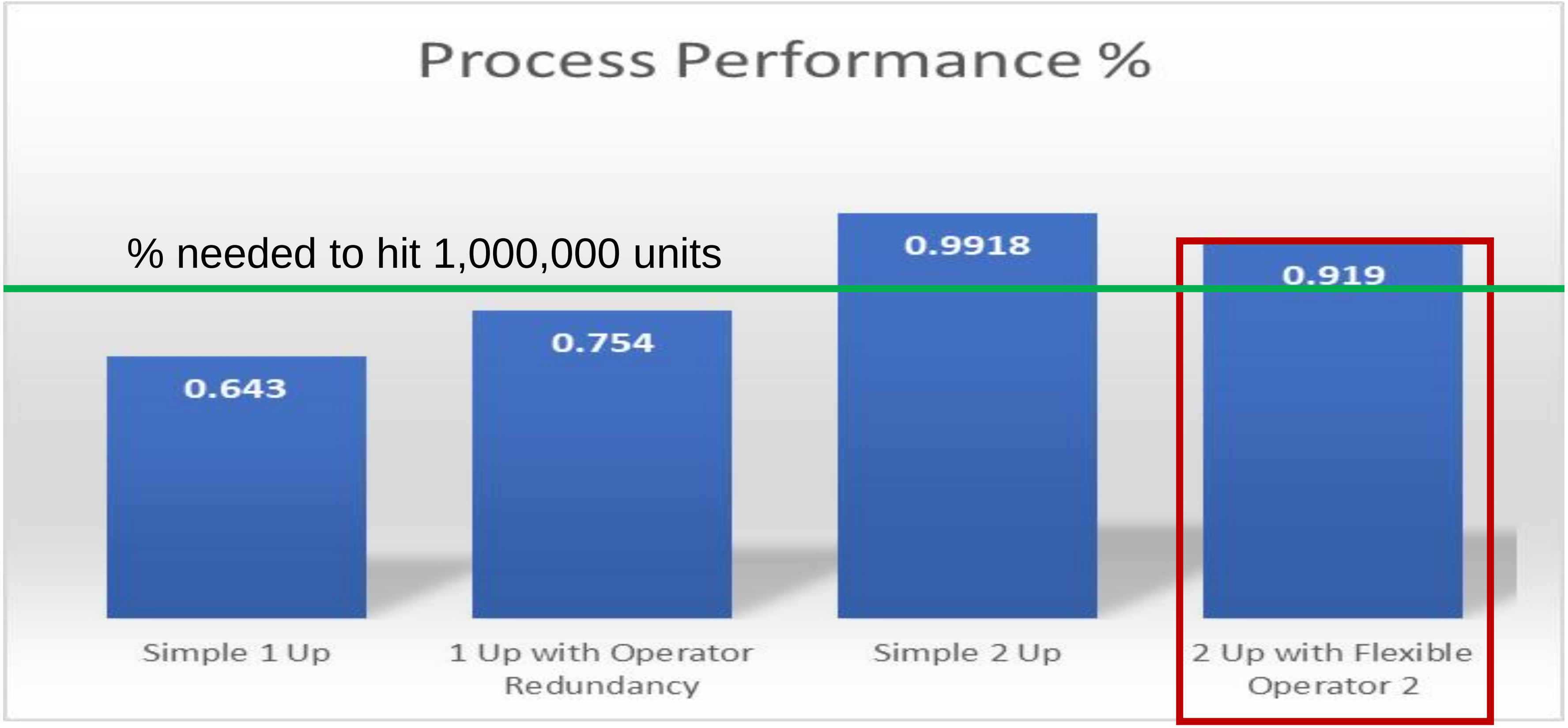
- The second operator is in parallel so the math changes per slide 4
  - Operator = 1-(1-.938)*(1-.979) = .9987
- Based on the math, we have improved the process performance to 75.4%
- But does that meet our requirement of 1 million units per year?
- .754*1.2 million= ~ 905,000. (still 95,000 short)

Next, assess adding a second tool/line per process step

									Machine 1		Machine 2	
Machine ID	**Operator ID**	**Overall Equipment**	**Machine**	**Machine 1**	**Machine 2**	**Operator**	**Operator 1**	**Operator 2**	**Total Days/ Year**	**Days Machine was available last year**	**Total Days/ Year**	**Days Machine was available last year**
CNC Mill 1	Operator 23, 24	0.99820	0.99950	0.88000	0.99583	0.99870	0.93750	0.97917	250	220	240	239
Deburr Station 1	Operator 19, 20	0.99475	0.99950	0.94000	0.99167	0.99525	0.92245	0.93878	250	235	240	238
Electropolish Line 1	Operator 7,8	0.99952	0.99953	0.94400	0.99167	0.99998	0.99592	0.99592	250	236	240	238
CMM 1	Operator 56,57	0.99957	0.99958	0.98000	0.97917	0.99998	0.99592	0.99592	250	245	240	235
Comparator 2	Operator 18,17	0.99982	0.99998	0.99600	0.99583	0.99983	0.99184	0.97959	250	249	240	239
Micrometer 23	Operator 67,68	0.99990	0.99998	0.99600	0.99583	0.99992	0.99592	0.97959	250	249	240	239
Process Performance %		0.9918										

- By adding a second tool/line in parallel per process step, we were able to bring the process performance up to 99.18%
- Is that enough?
  - .9918*1.2 Million= ~1,190,000, (more than enough)
  - Too much, use the template to back solve for 1,000,000
- Having 1 extra machine/line in parallel is not feasible
- The goal however is to validate a second piece of equipment for each process step to enable redundancy and freedom to operate.

Capacity is too high so run some "what-if" scenarios



- Is that still enough? .919* 1.2 million = ~1,103,000 (surprisingly yes)
- What-if…the second operators each had a ~ 80% attendance rate?
- Simply type it in and see what the model says. Easy.

Averages are nice and variation is enlightening

	Simple 1 Up	1 Up with Operator Redundancy	Simple 2 Up	2 Up with Flexible Operator 2
Machine ID	**Overall Equipment (Days)**	**Overall Equipment (Days)**	**Overall Equipment (Days)**	**Overall Equipment (Days)**
CNC Milling	0.825	0.879	0.9982	0.9683
Deburring	0.867	0.936	0.9948	0.9600
Electropolish	0.940	0.944	0.9995	0.9975
CMM Inspect	0.976	0.980	0.9996	0.9975
Comparator Inspect	0.988	0.996	0.9998	0.9958
Micrometer Inspect	0.992	0.996	0.9999	0.9979
Process Flow Perf Estimate	64.32%	75.43%	99.18%	91.90%

Average Number of Days the Process Runs	160.80	188.59	247.94	229.75
Simulated Binomial Distribution	161.00	189.00	248.00	230.00
Stdev	7.57	6.81	1.43	4.31
Simulated Standard Deviation	7.57	6.81	1.43	4.31
Avg-3 Stdev	138.08	168.17	243.66	216.81
Rounded Down	138.00	168.00	243.00	216.00

- Build the serial & parallel circuit math into the manufacturing template
- This enables simulations to be run at Summary Tab level instead
- Average Number of days the process runs =RiskBinomial(250,.643)*
- *Software used was @Risk, an Excel add-in.

Capacity Planning Templates

Increase collaboration

Enable “what-if” scenarios

Enable shared assumptions for capacity

Costing Tools

Time tracking templates enable statistical cost modeling

ABC Rate	CNC Mill:	Lot 1	Lot 2	Lot 3	MinCost	AvgCost	MaxCost
$75	Setup Time	30	27	28	$33.75	$35.42	$37.50
$35	Cycle Time	5	3	6	$875.00	$1,361	$1,750
	Deburr Station:						
$30	Setup Time	10	8	5	$2.50	$3.83	$5.00
$20	Cycle Time	12	11	13	$1,833	$2,000	$2,167
	Electropolish Line:						
$70	Setup Time	35	25	30	$29	$35	$41
$35	Cycle Time	10	9	8	$2,333	$2,625	$2,917
	CMM:						
$65	Setup Time	32	30	31	$33	$34	$34.7
$30	Cycle Time	5	3	4	$750	$1,000	$1,250
	Comparator:						
$40	Setup Time	25	22	21	$14	$15	$17
$25	Cycle Time	7	5	6	$1,042	$1,250	$1,458
	Micrometer:						
$25	Setup Time	8	6	4	$1.67	$2.50	$3.33
$20	Cycle Time	3	5	6	$500	$778	$1,000
*	**Setup Time Only**				$114	$125	$138
	Cycle Time Only				$7,333	$9,014	$10,542
	Material Only				$1,000	$1,000	$1,000
	Total Material and Labor				$8,333	$10,014	$11,542
	Part Cost				$16.67	$20.03	$23.08

*

ABC Rate stands for Activity-Based Costing

Record min (green) and max (red) times for each process step

Monte Carlo simulation software adds extra tools

ABC Rate	CNC Mill:	Lot 1	Lot 2	Lot 3	MinCost	Cost	MaxCost	Uniform Cost	Triangular Cost	Pert Cost	Normal Cost
$75	Setup Time	30	27	28	$33.75	$35.42	$35.42	$35.63	$35.56	$35.49	$35.42
$35	Cycle Time	5	3	6	$875.00	$1,361.11	$1,750.00	$1,312.50	$1,328.70	$1,344.91	$1,361.11
	Deburr Station:										
$30	Setup Time	10	8	5	$3	$4	$4	$3.75	$3.78	$3.81	$3.83
$20	Cycle Time	12	11	13	$1,833	$2,000	$2,167	$2,000.00	$2,000.00	$2,000.00	$2,000.00
	Electropolish Line:										
$70	Setup Time	35	25	30	$29	$35	$35	$35.00	$35.00	$35.00	$35.00
$35	Cycle Time	10	9	8	$2,333	$2,625	$2,917	$2,625.00	$2,625.00	$2,625.00	$2,625.00
	CMM:										
$65	Setup Time	32	30	31	$33	$34	$34	$33.58	$33.58	$33.58	$33.58
$30	Cycle Time	5	3	4	$750	$1,000	$1,250	$1,000.00	$1,000.00	$1,000.00	$1,000.00
	Comparator:										
$40	Setup Time	25	22	21	$14	$15	$15	$15.33	$15.26	$15.19	$15.11
$25	Cycle Time	7	5	6	$1,042	$1,250	$1,458	$1,250.00	$1,250.00	$1,250.00	$1,250.00
	Micrometer:										
$25	Setup Time	8	6	4	$2	$3	$3	$2.50	$2.50	$2.50	$2.50
$20	Cycle Time	3	5	6	$500	$778	$1,000	$750.00	$759.26	$768.52	$777.78
	Setup Time Only				$113.58	$125.44	$125.44	$125.79	$125.68	$125.56	$125.44
	Cycle Time Only				$7,333.33	$9,013.89	$10,541.67	$8,937.50	$8,962.96	$8,988.43	$9,013.89
	Material Only				$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,001.00	$1,002.00	$1,003.00
	Total Material and Labor				$8,333.33	$10,013.89	$11,541.67	$10,063.29	$10,089.64	$10,115.99	$10,142.33
	Part Cost				$16.67	$20.03	$23.08	$20.13	$20.18	$20.23	$20.28

Uniform and Normal distributions are common in tolerance stackups
Triangle and Pert distributions are common in project management

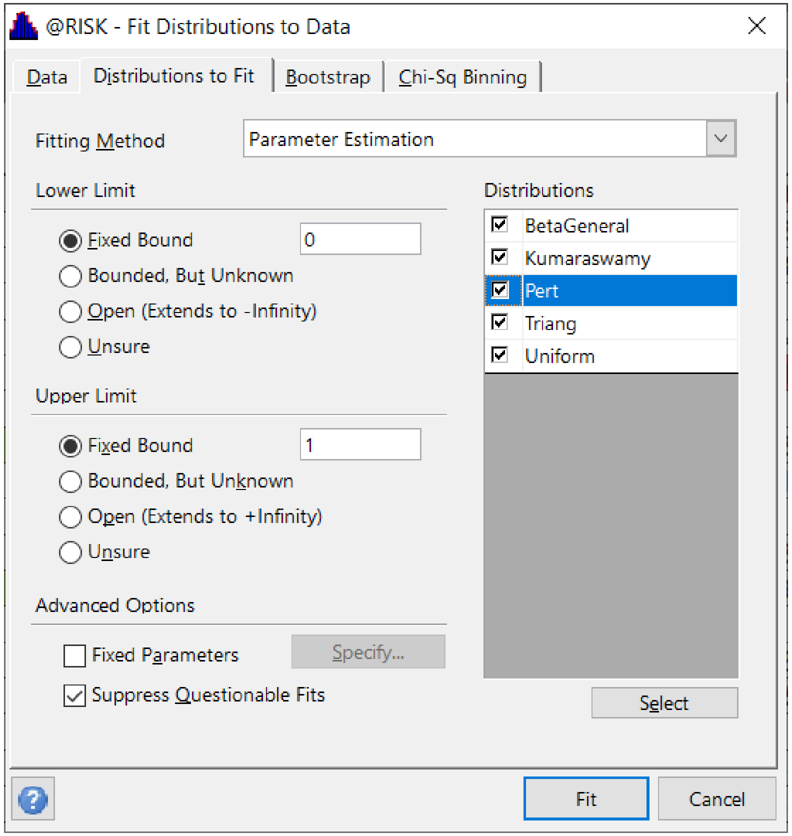
The software can also custom fit distributions to rows

ABC Rate	CNC Mill:	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 9	Lot 10	Lot 11	Lot 12	Lot 13	Lot 14	Lot 15	MinCost	Cost	MaxCost	Fit Distribution Cost
$75	Setup Time	30	27	28	29	30	29	30	28	27	26	32	34	35	36	37	$32.50	$38.17	$46.25	$38.01
$35	Cycle Time	5	3	6	6	5	2	4	5	6	7	8	9	3	5	6	$583.33	$1,555.56	$2,625.00	$1,559.75
	Deburr Station:																			
$30	Setup Time	10	8	5	4	3	5	3	2.5	6	5	4	3.5	5	6	6	$1	$3	$3	$2.65
$20	Cycle Time	12	11	13	13	9	12	11	12	13	14	15	10	12	13	12	$1,500	$2,022	$2,500	$2,003.59
	Electropolish Line:																			
$70	Setup Time	35	25	30	31	32	32	35	40	40	39	38	37	38	40	42	$29	$42	$49	$41.49
$35	Cycle Time	10	9	8	9	8	4	6	3	5	11	10	8	9	8	10	$875	$2,294	$3,208	$2,300.56
	CMM:																			
$65	Setup Time	32	30	31	33	29	28	26	27	28	29	31	32	30	31	32	$28	$32	$35	$31.96
$30	Cycle Time	5	3	4	4	5	4	6	3.5	5	5	6	4	7	6	5	$750	$1,208	$1,750	$1,250.00
	Comparator:																			
$40	Setup Time	25	22	21	23	25	26	23	24	25	26	27	28	25	26	23	$14	$16	$16	$16.33
$25	Cycle Time	7	5	6	5	3	4	7	8	6	7	5	6	5	6	2.5	$521	$1,146	$1,667	$1,093.75
	Micrometer:																			
$25	Setup Time	8	6	4	6	5	5	5.5	6	4.5	5.5	6.5	6	4	3	5	$1	$2	$2	$2.23
$20	Cycle Time	3	5	6	3	5	4.5	3	3.5	3	4	3.5	4	3	2.5	4	$417	$633	$1,000	$637.45

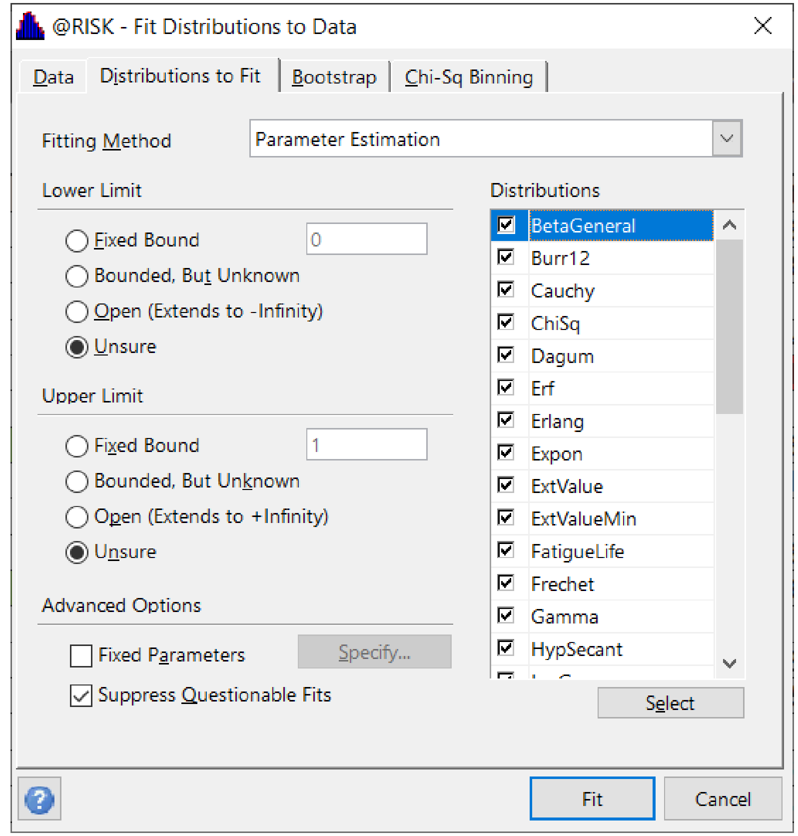
	MinCost	Cost	MaxCost	Fit Distribution Cost
Setup Time Only	$106.33	$133.28	$151.54	$132.66
Cycle Time Only	$4,645.83	$8,859.72	$12,750.00	$8,845.10
Material Only	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Total Material and Labor	$5,645.83	$9,859.72	$13,750.00	$9,977.76
Part Cost	$11.29	$19.72	$27.50	$19.96

Items in (green) are moments of excellence
Items in (red) are moments of non-excellence
We learn from both !

The “fit distribution” function has four bounding options

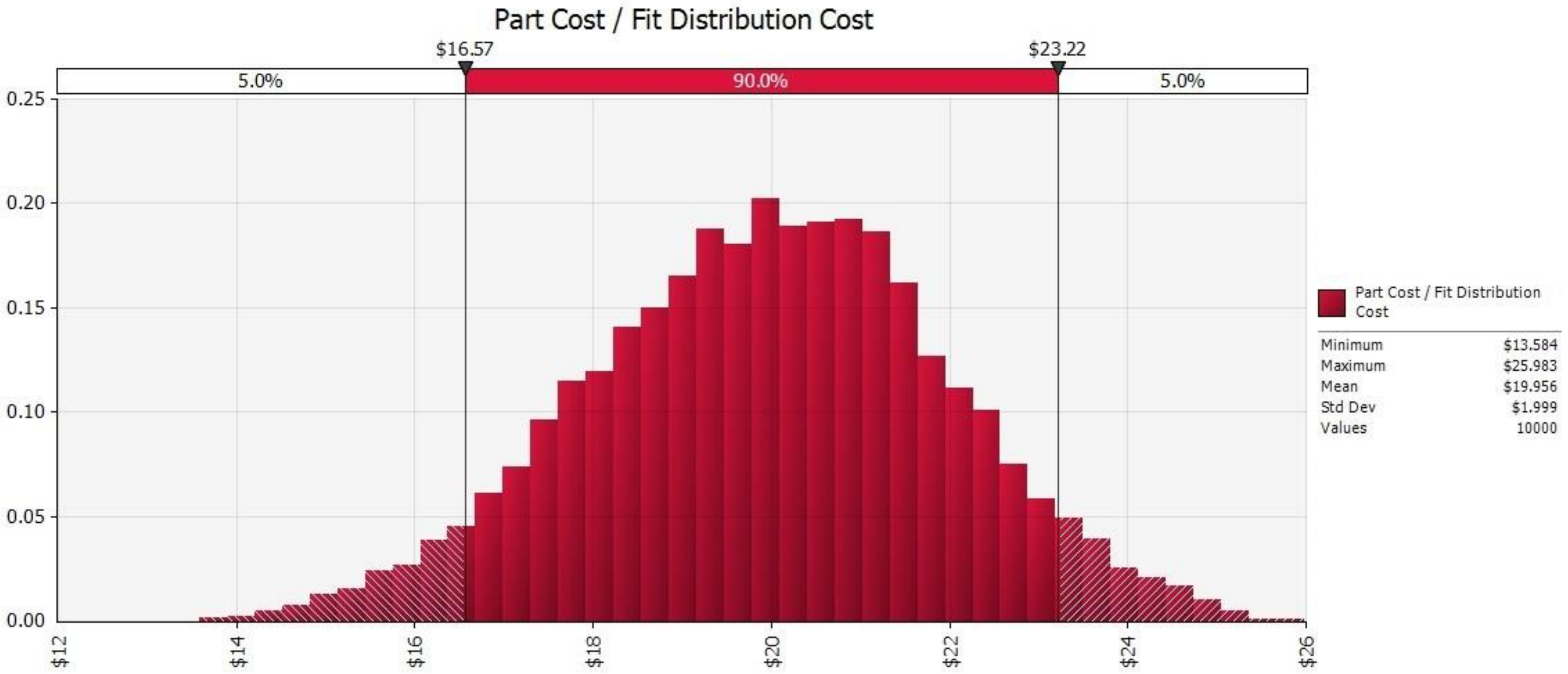


Fixed Bounds Tempting
But Dangerous



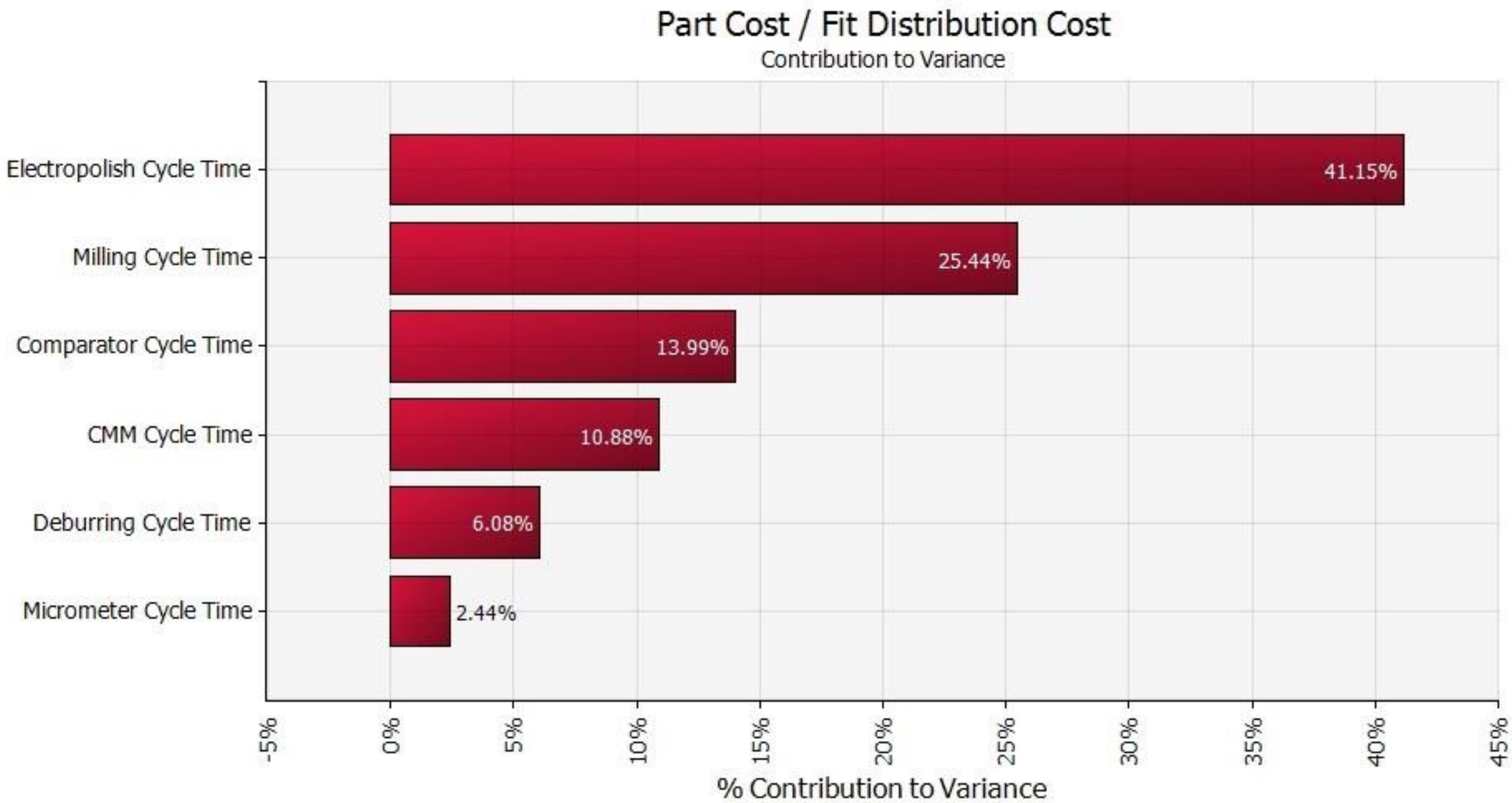
Unsure Bounds opens
many distributions

One payoff for statistical cost modeling: graphical outputs



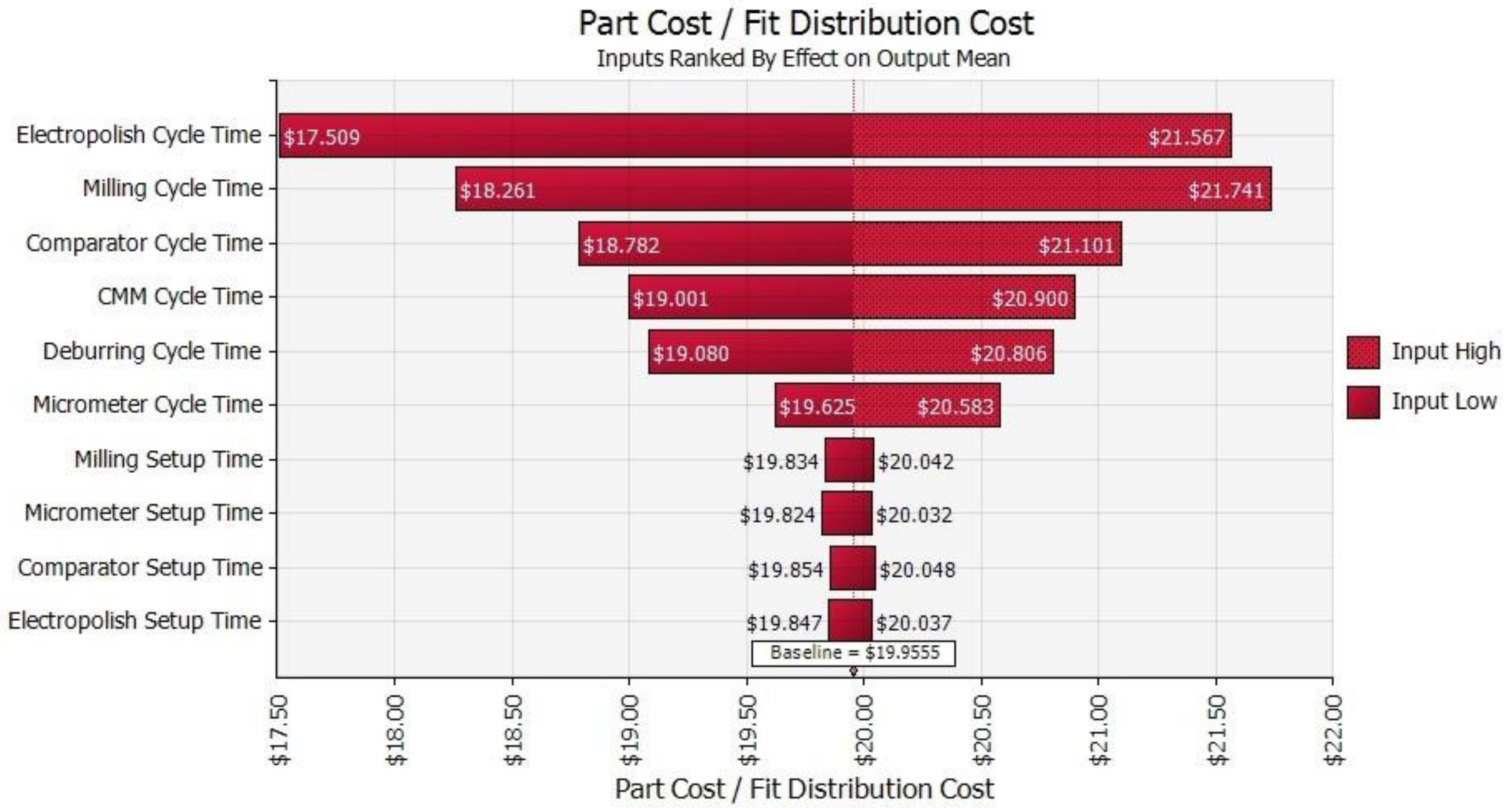
The first graphic is the histogram which gives mean, stdev, min and max
This is very useful to check for assumptions in the model and central limit theorem

The % Contribution to Variance plot is always enlightening



Activity based costing enables a variable costs * distribution model
Compare to the all costs are $50 per hour * distribution model

Ranked effect plots are useful in a +/- cost notation



This is where we learn about how the setup costs impact part cost

Costing Templates

Enable moments of excellence and standard work

Create a data-based methodology for costing

Create a core competency for costing of new products

So, today we discussed:

- Using network reliability theory to give a new perspective on capacity planning
- Showed how to use reliability theory to model a manufacturing cell at a high level using a binominal distribution in the @Risk software
- Showed how we could use @Risk to fit distributions to historical data to create better cost models.
- and thus improve profitability

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Thank You