

ROBUST DESIGN AND RISK

1. Robust Design

- definitions
- simple example: two points = a line?
- engineering example: pipe flow
- more engineering examples
- applications to “quality”

2. Risk

- global and local

1. DEFINITIONS

ro·'bust ('ro·,bust) [*adj*; Latin *robustus* oaken, strong]

- having or exhibiting strength or vigorous health
- strongly formed or constructed
- strong enough to withstand or overcome intellectual challenges or adversity

Statistics

A *median* (50th percentile) is robust

A *mean* (common average) is not

In 10 years, will your graduating class be happy with an average income of \$100,000?

Statistics

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In 10 years, will your graduating class be happy with an average income of \$100,000?

1 @ \$50,000,000
999 @ \$50,050

Average: \$100,000

Median: \$50,050

Happy now?

Robust Design

- strong *(oops, I dropped it)*
- and
- simple *(Murphy's Law)*
- efficient
- flexible
- idiot-proof *(Murphy was an optimist)*
- etc.

[Murphy's Law: whatever can go wrong, will go wrong.]

Q: Is there “failure to warn” liability for **unintended use**?

A: Only if
“Reasonably foreseeable”



[<http://www.geekologie.com/2010/07/28/lawnmower-man.jpg>]



[<http://www.geekologie.com/2009/11/17/extreme-mowing.jpg>]

A *robust* device, system, or process...

“performs as intended even under

non-ideal conditions such as

manufacturing process variations or

a range of operating situations”

– Ulrich-Eppinger, p. 201

non-ideal conditions = *noise*

– functional (e.g., diameter of bolt and bolt hole)

– environmental (e.g., temperature)

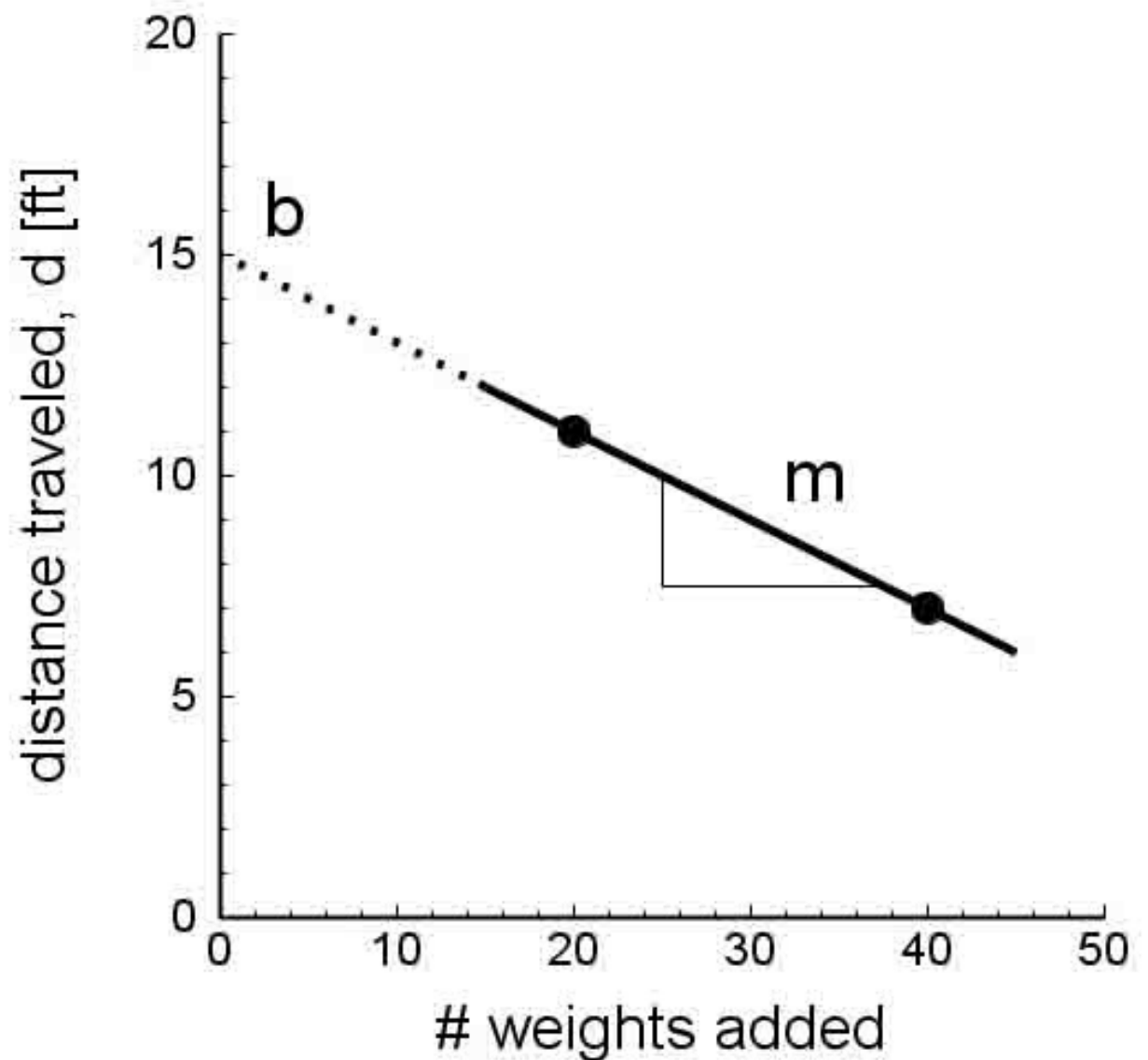
= uncontrolled variations

(including accidents and unintended use)

2. EXAMPLE: TWO POINTS = A LINE?

Calibration
curve for
mousetrap car
based on
two tests
(points)

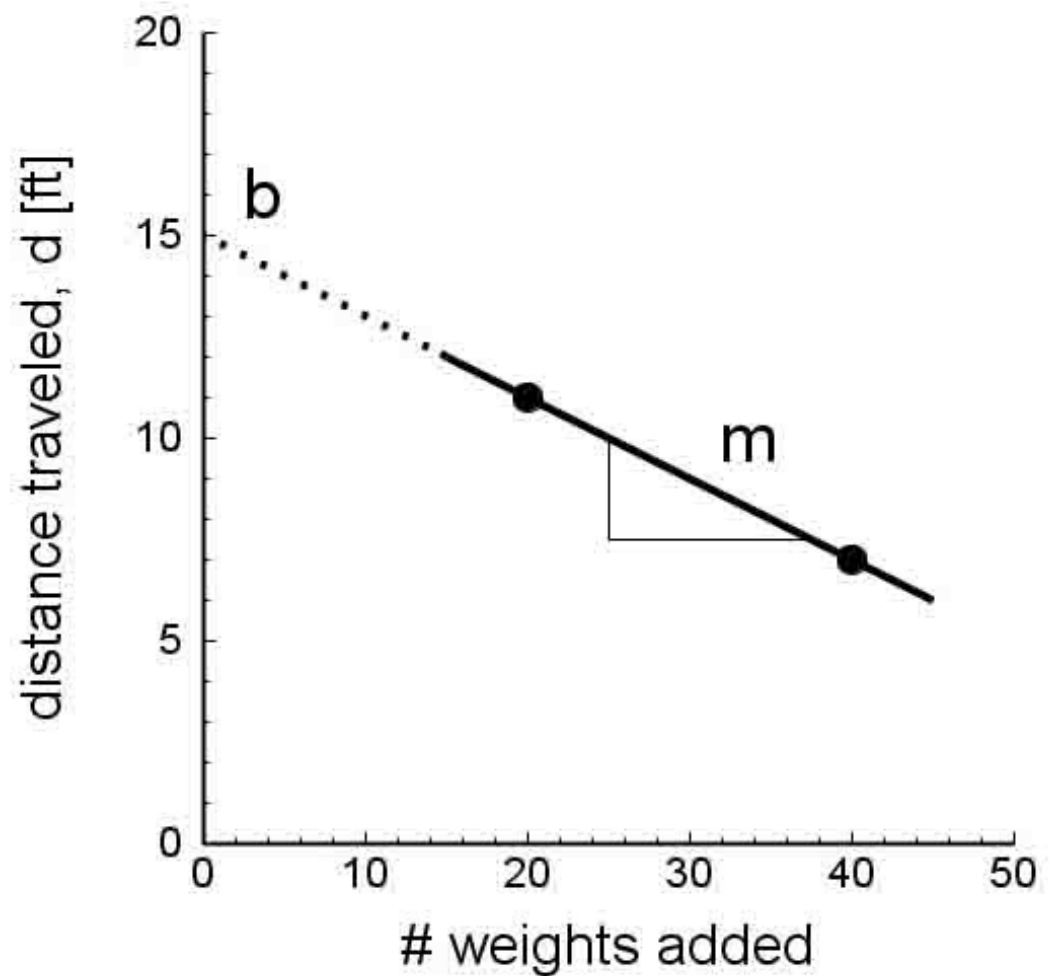
“ $y = mx + b$ ”



Think like an engineer

Could the true calibration curve be linear?

- A. Yes
- B. No
- C. Not enough information



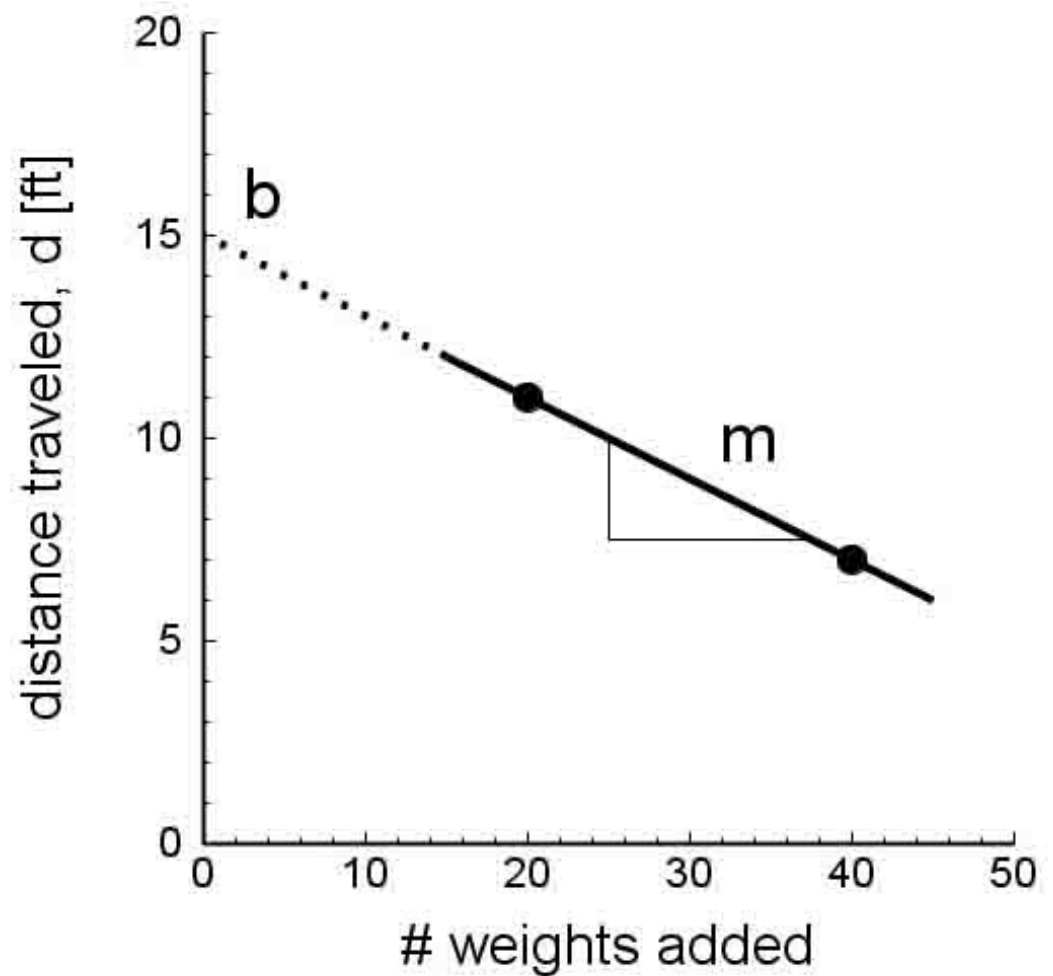
Think like an engineer

Could the true calibration curve be linear?

B. No ✓

weights = 500

⇒ car goes
backwards

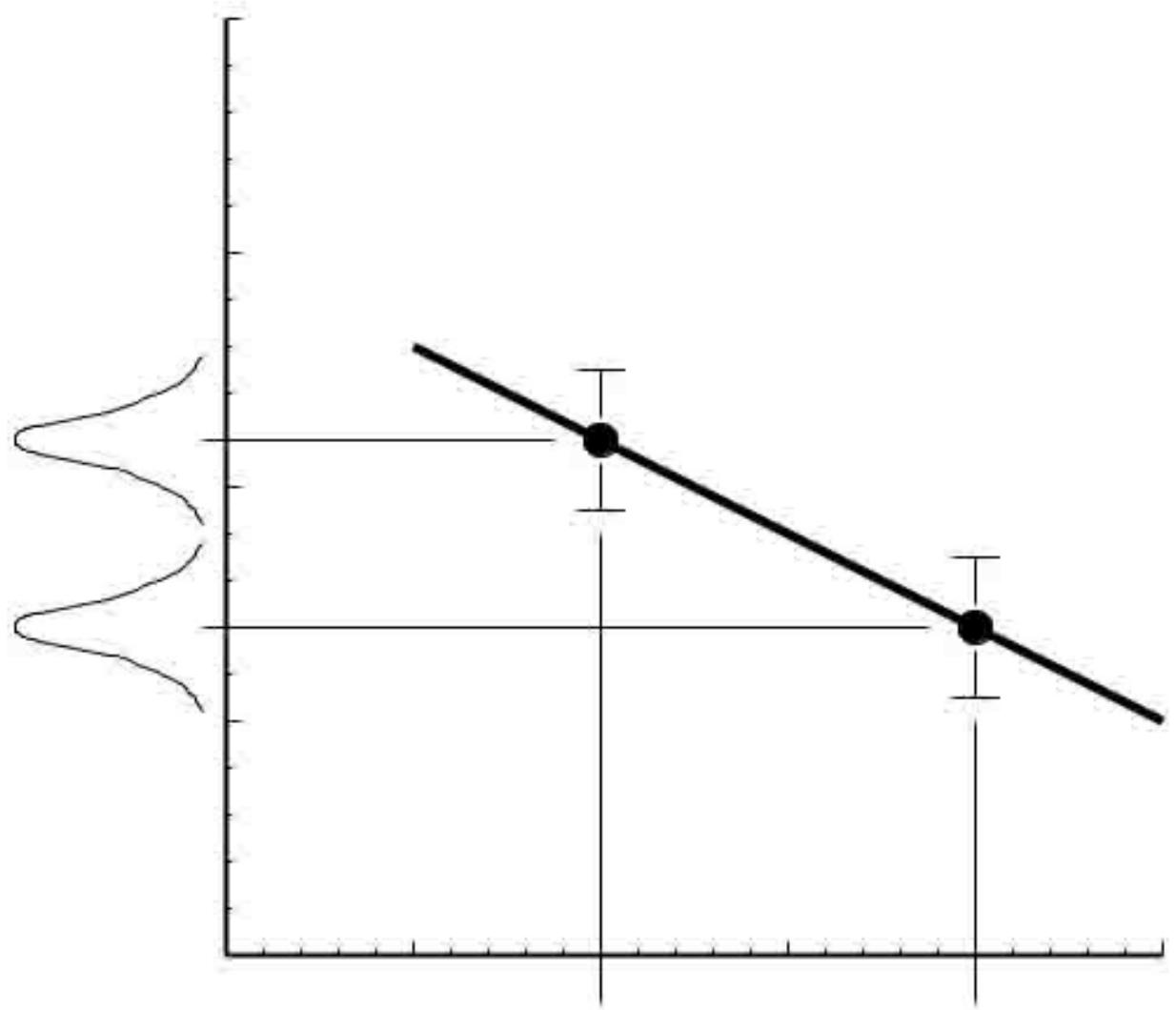


Reality (still two points; piecewise linear)

Repeat the tests with the two weights

There will be variations in the response

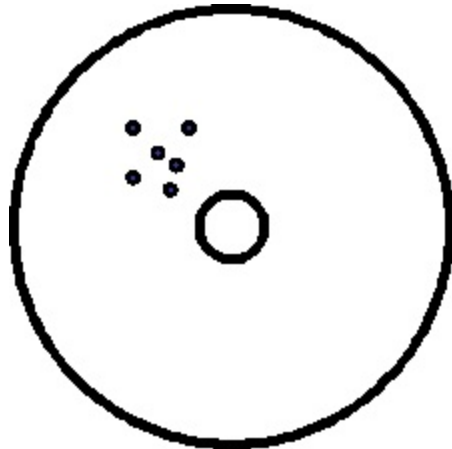
Why? *Noise*.



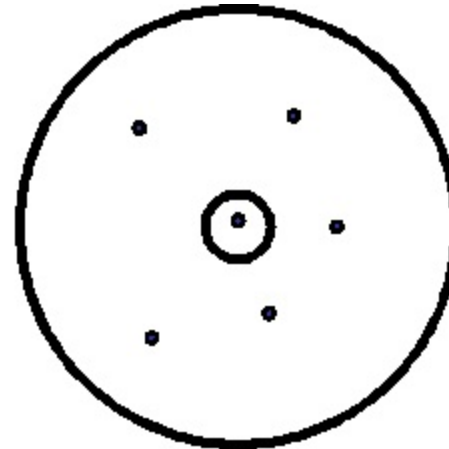
non-ideal conditions = *noise*

- functional
 - right before testing, did you:
 - relubricate your axles?
- environmental
 - would your mini-projects have performed exactly the same if the room temperature was 90°F?

Who is the Better Target Shooter?



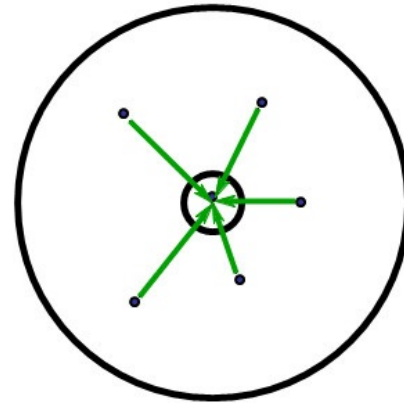
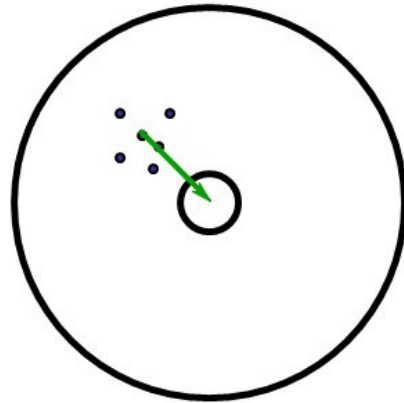
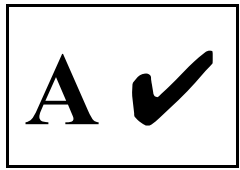
A: Sam



B: John

Choose **A** (Sam) or **B** (John).

Who is the Better Target Shooter?

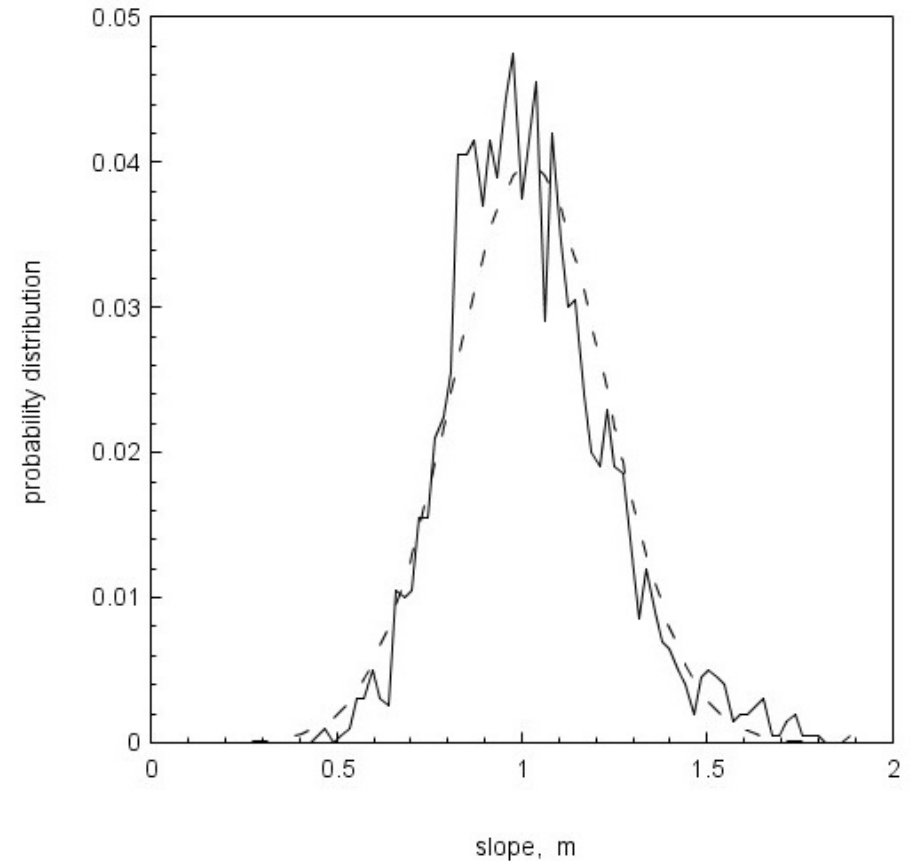
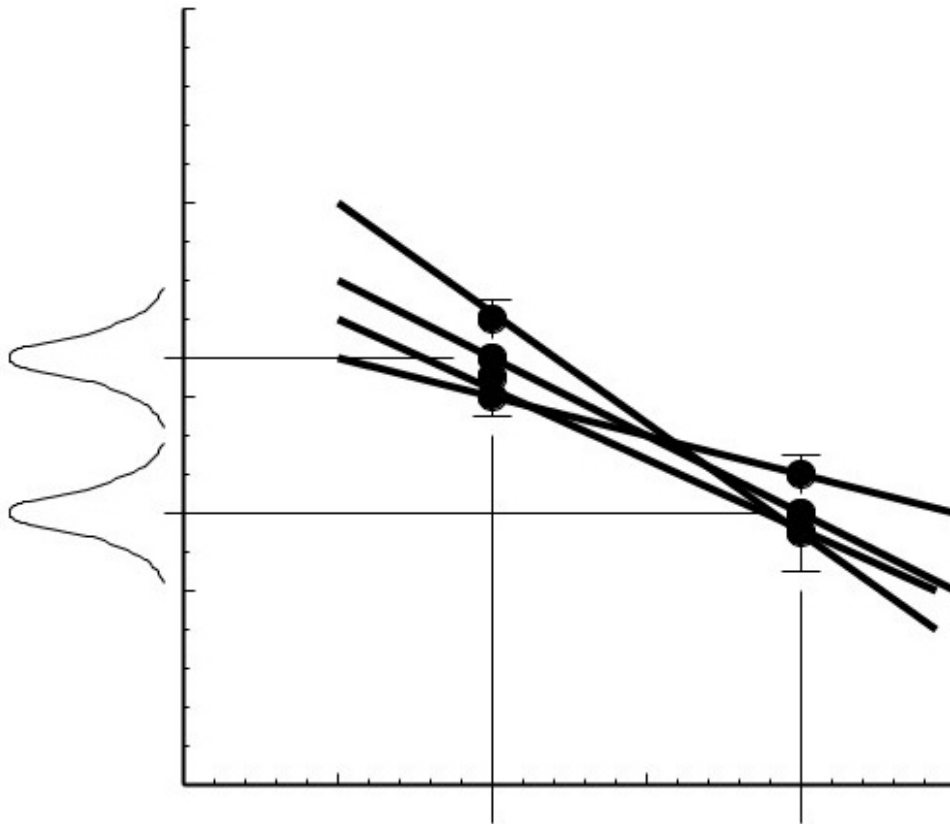


A is better

Sam only needs to calibrate better.

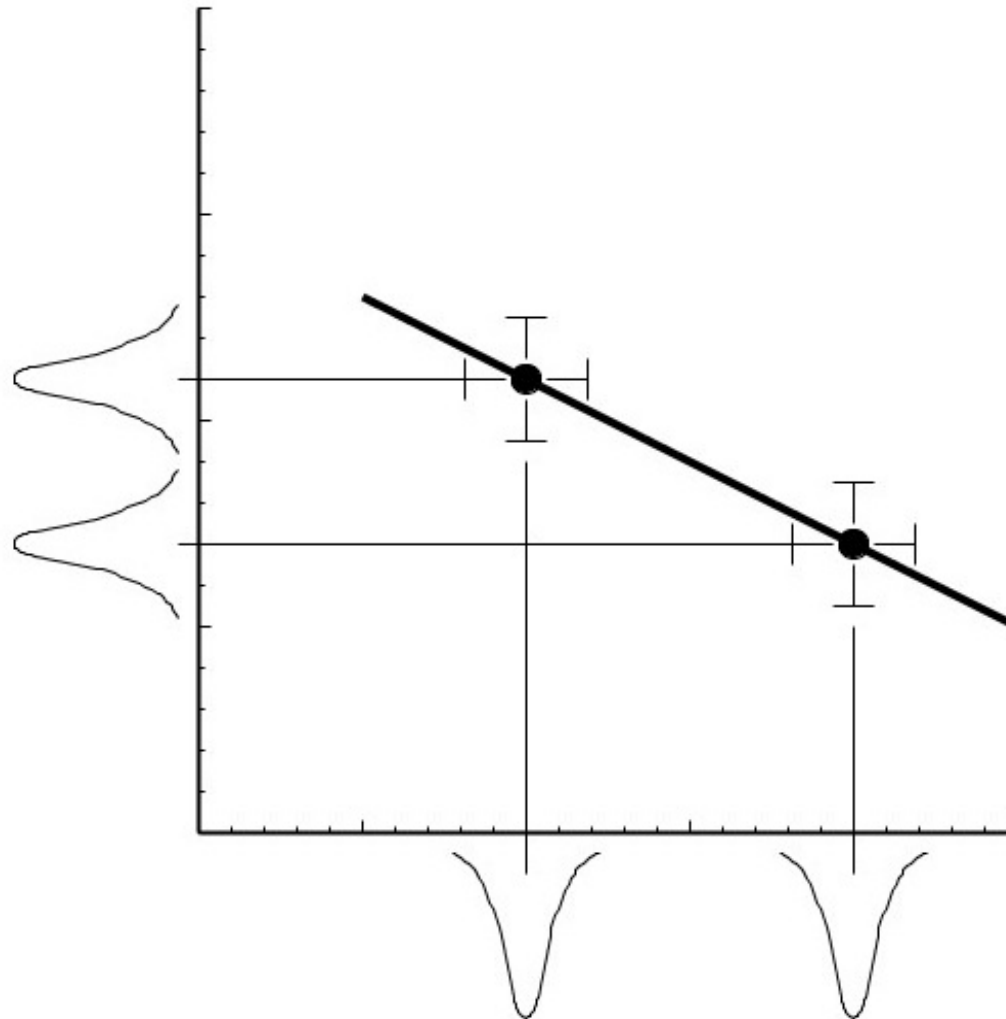
John needs to find and reduce *noise* (functional and/or environmental).

You calibration curve,
if you only measured the two points once, with **noise**



You need to find and reduce effect of noise.

What if you input **noise** into the system?

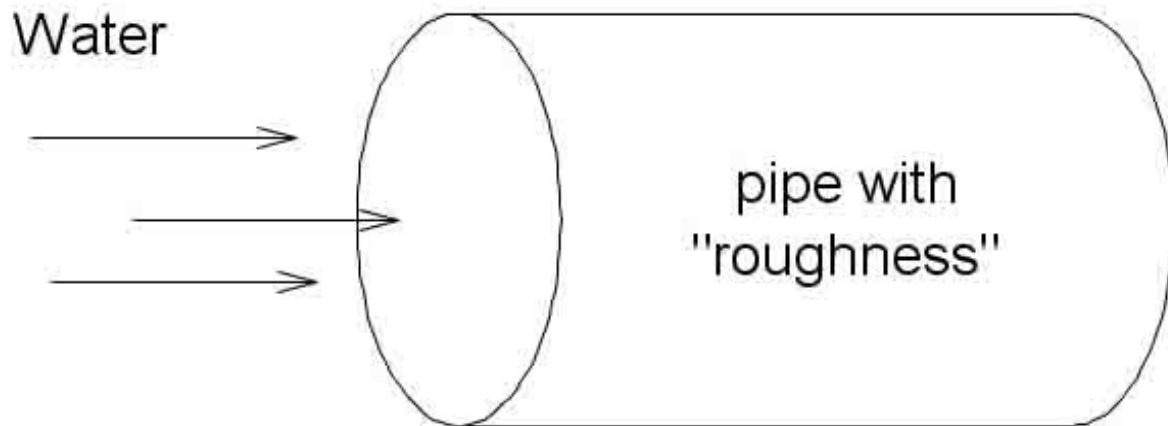


3. EXAMPLE: PIPE FLOW

- you may need a pump

$$\dot{W} [W] = v[m/s] \left(\frac{\pi (D[m])^2}{4} \right) \Delta P [Pa]$$

- maybe there's roughness in the pipe
⇒ friction ⇒ pressure drop, ΔP



Pressure drop in a pipe due to friction

$$\Delta P = f \frac{L}{D} \frac{\rho v^2}{2}$$

Friction factor, f — from the *Haaland Equation*

$$f = \left\{ -1.8 \log_{10} \left[\left(\frac{\varepsilon / D}{3.7} \right)^{1.11} + \frac{6.9 \mu}{\rho D v} \right] \right\}^{-2}$$

Plug, chug, cobble together, and deploy your amazing engineered water system...

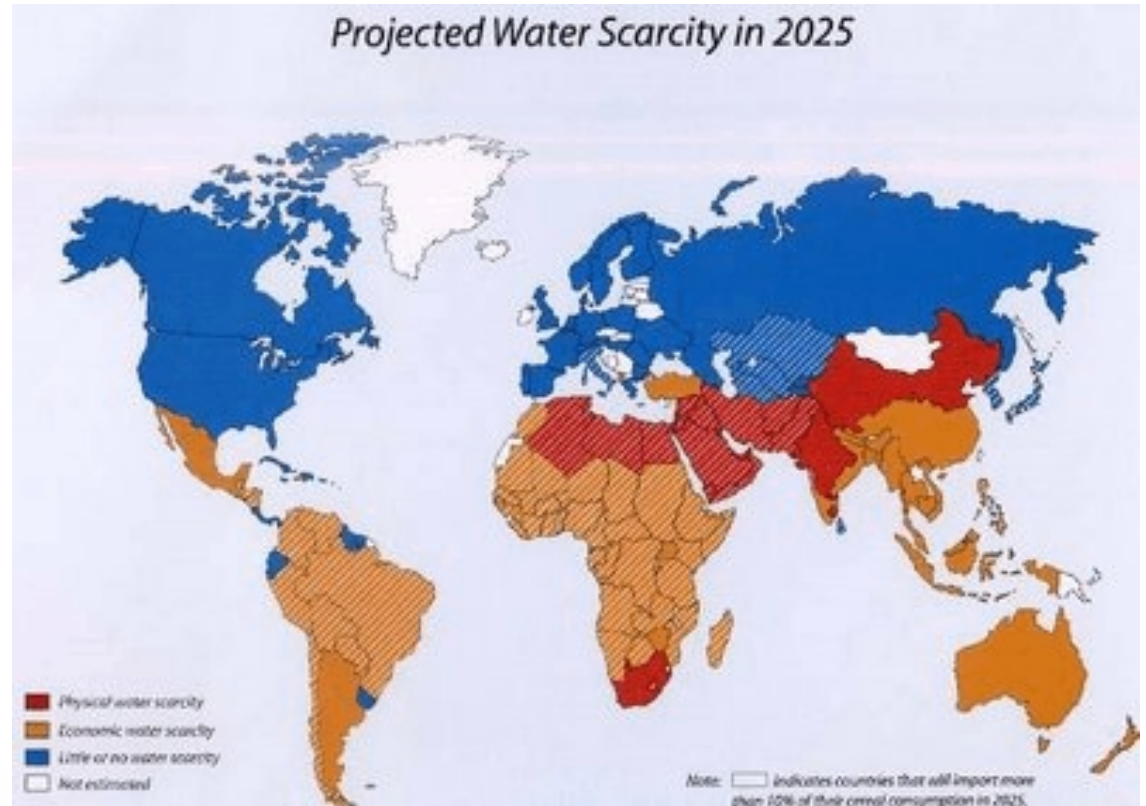
Today...



Your design works.

You're a hero.

Tomorrow...



Did you start a war?

Was your computation of the friction factor robust?

	rho =	999.2 kg/m ³	water density at 20 deg C					
	mu =	9.85E-004 N.s/m ²	water viscosity at 20 deg C					
	L =	200 m	length of pipe					
material	e [mm]	D [m]	v [m/s]	m-dot [kg/s]	f [-]	DP [Pa]	W-dot [W]	gpm
extreme	0	0.1	0.1	0.8	0.031	307	0.24	12.4
glass	0.001	0.1	0.1	0.8	0.031	307	0.24	12.4
stainless steel	0.03	0.1	0.1	0.8	0.031	311	0.24	12.4
cast iron	0.3	0.1	0.1	0.8	0.035	348	0.27	12.4
concrete	1	0.1	0.1	0.8	0.043	429	0.34	12.4
riveted steel	3	0.1	0.1	0.8	0.060	602	0.47	12.4
extreme	30	0.1	0.1	0.8	0.212	2119	1.66	12.4

$$f = \left\{ -1.8 \log_{10} \left[\left(\frac{\varepsilon/D}{3.7} \right)^{1.11} + \frac{6.9\mu}{\rho D v} \right] \right\}^{-2}$$

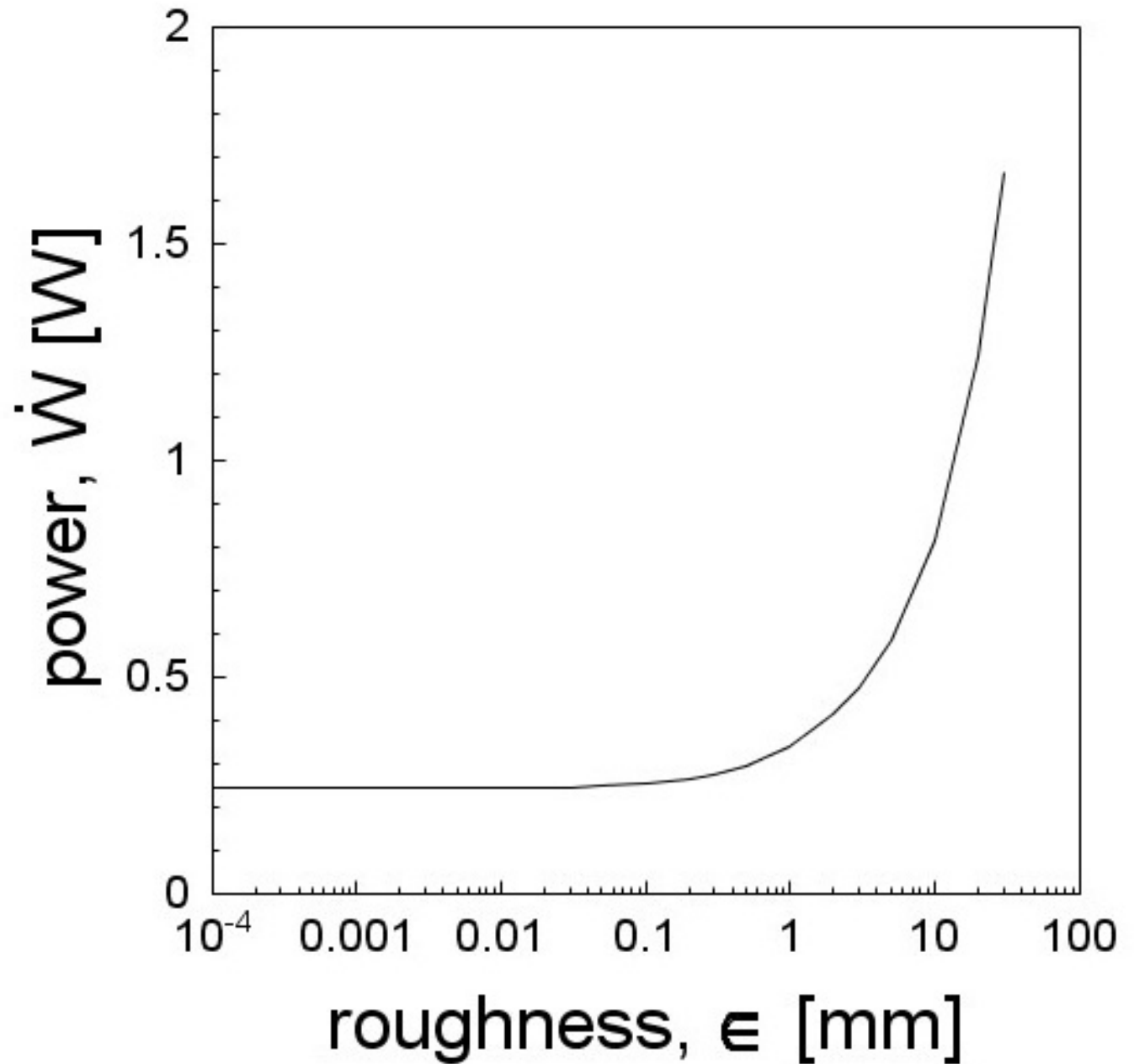
$$\Delta P = f \frac{L}{D} \frac{\rho v^2}{2}$$

$$\dot{W} [W] = v [m/s] \left(\frac{\pi (D[m])^2}{4} \right) \Delta P [Pa]$$

$$\dot{m} = \rho v \left(\frac{\pi D^2}{4} \right)$$

You can plot
this variation,
and see
something
useful

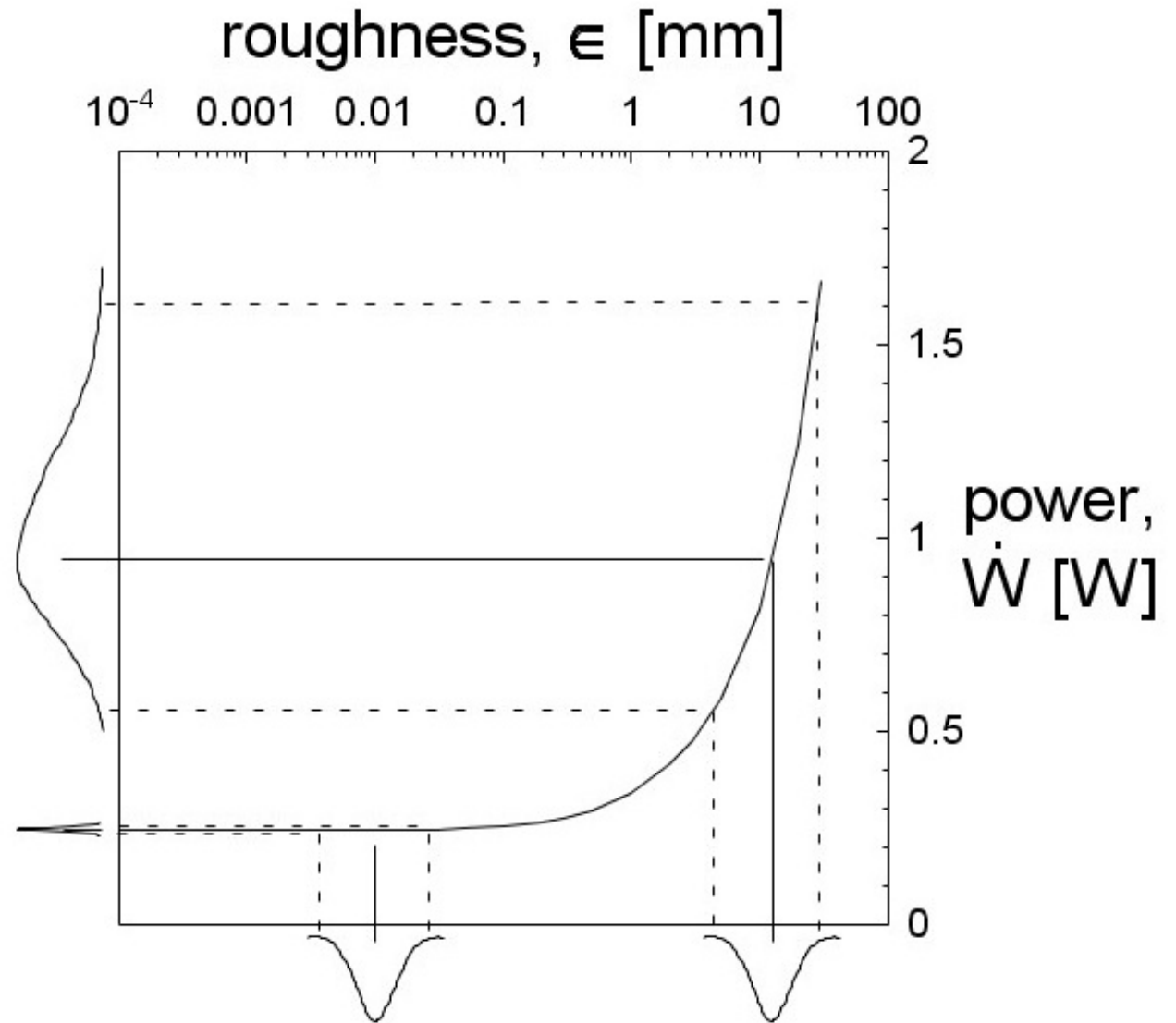
Variation in ϵ
causes
relatively small
variation in \dot{W} ,
except in the
extreme.



If you know the roughness is small, you don't need to know the roughness well.



A design with smaller roughness is more robust



What about the other variables?

	rho =	999.2	kg/m ³	water density at 20 deg C				
	mu =	9.85E-004	N.s/m ²	water viscosity at 20 deg C				
	L =	200	m	length of pipe				
material	e [mm]	D [m]	v [m/s]	m-dot [kg/s]	f [-]	DP [Pa]	W-dot [W]	gpm

copper -	0.01	0.1	0.1	0.8	0.031	308	0.24	12.4
copper	0.03	0.1	0.1	0.8	0.031	311	0.24	12.4
copper +	0.1	0.1	0.1	0.8	0.032	320	0.25	12.4
copper -	0.01	0.05	0.1	0.2	0.038	754	0.15	3.1
copper	0.03	0.05	0.1	0.2	0.038	761	0.15	3.1
copper +	0.1	0.05	0.1	0.2	0.039	789	0.15	3.1
copper -	0.01	0.05	0.4	0.8	0.026	8312	6.53	12.4
copper	0.03	0.05	0.4	0.8	0.027	8559	6.72	12.4
copper +	0.1	0.05	0.4	0.8	0.029	9405	7.39	12.4

D↓: lose flow rate, or lose money on pump?

4. MORE EXAMPLES

Robust \Rightarrow Flexible

Oh, sure: that's great...

if you have the equations!

So what if you don't?

The three methods of analysis

- analytical \leftarrow limited
- numerical \leftarrow expensive
- **experimental** \leftarrow more expensive,
more insightful

Sustainable can-openers?

Table 1: Decision Matrix Comparing Electric and Manual Can Openers

Keywords: Weight:	Convenience 40%	Cost 30%	Reliability 30%	Overall** 100%
Electric	8*	4	6	6.2
Manual	5	9	7	6.8

* product ratings are focus group assessments on a 0-10 scale

** sample calculation: $8(0.4) + 4(0.3) + 6(0.3) = 6.2$

What is your confidence that you've made the right choice?

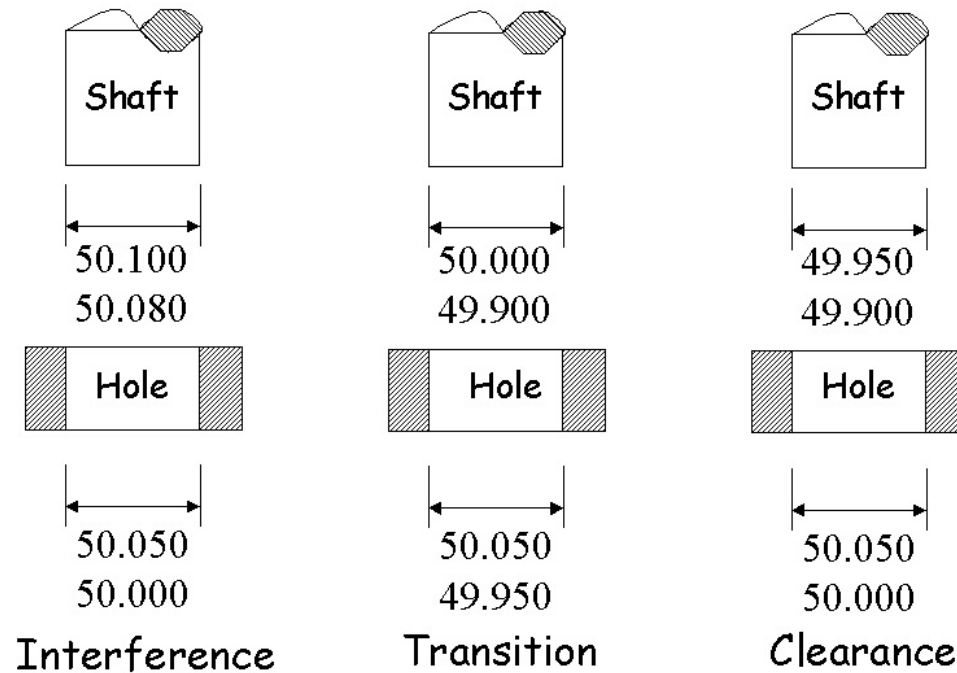
Tolerance Analysis on Decision Matrix

	convenience	cost	reliability				convenience	cost	reliability	
	40%	30%	30%	100%			40%	30%	30%	100%
electric	8	4	6	6.2		electric	8	4	6	6.2
manual	5	9	7	6.8		manual	5	9	7	6.8
	40%	30%	30%	100%			50%	20%	30%	100%
electric	9	4	6	6.6		electric	8	4	6	6.6
manual	5	9	7	6.8		manual	5	9	7	6.4
	40%	30%	30%	100%			50%	30%	20%	100%
electric	8	4	6	6.2		electric	8	4	6	6.4
manual	4	9	7	6.4		manual	5	9	7	6.6

Now how confident are you?

Geometric Tolerancing

http://www.mech.uq.edu.au/courses/mech2110/standard_fits/index.html



interference fit:

$$\text{shaft} - \sigma_{\text{shaft}}^{-} \geq \text{hole} + \sigma_{\text{hole}}^{+}$$

transition fit:

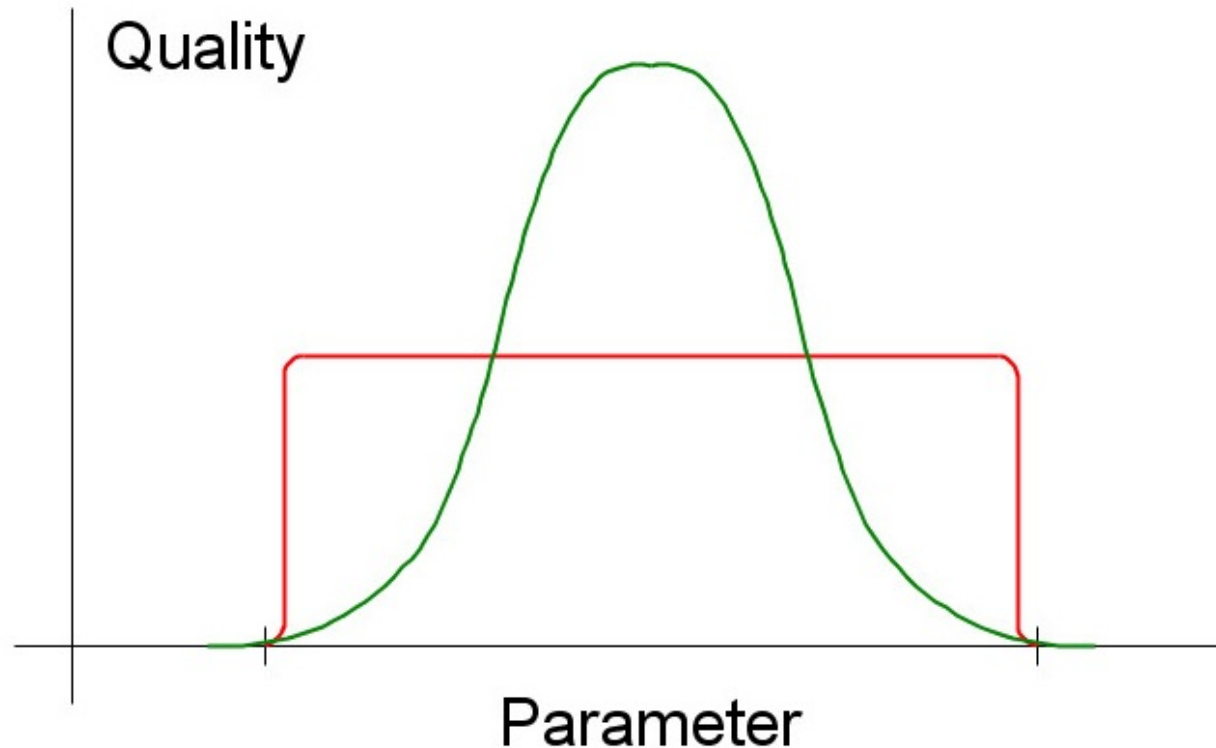
in between

clearance fit:

$$\text{shaft} + \sigma_{\text{shaft}}^{+} \leq \text{hole} - \sigma_{\text{hole}}^{-}$$

5. APPLICATIONS TO “QUALITY”

Which is better: **to meet the specification**
or **to hit the target**



Genichi Taguchi

engineer... who later became a statistician

Did what statisticians had been saying for decades...

but did it with the vocabulary of engineers

Quality is related to the total loss to society due to the response of a given product to noise.

*Quality is related to the total loss to society due to the response of a given product to *noise*.*

Quantify Quality

Signal-to-noise ratio: SNR or **S/N**

$S/N > 1 \Rightarrow$ more signal than noise

Investigate Quality

Orthogonal Arrays (see text)

Methods for Investigating Quality

- tolerance analysis (examples above)
lower cost, higher precision, not as robust
(underestimates variation if significant sources of noise are not included)
- “Taguchi” methods (see text)
higher cost, lower precision, much more robust
- response surface methodologies
gives better insight into the “directions” to
adjust parameters to get optimally robust
designs
- and more....

The design objective:

Find a *setpoint*

(a combination of design parameter values)

that maximizes quality

in the presence of

functional and environmental **noise**.

molto robusto

