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·ˈbust (ˈro·ˌbust) [*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* (50^{th} 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)

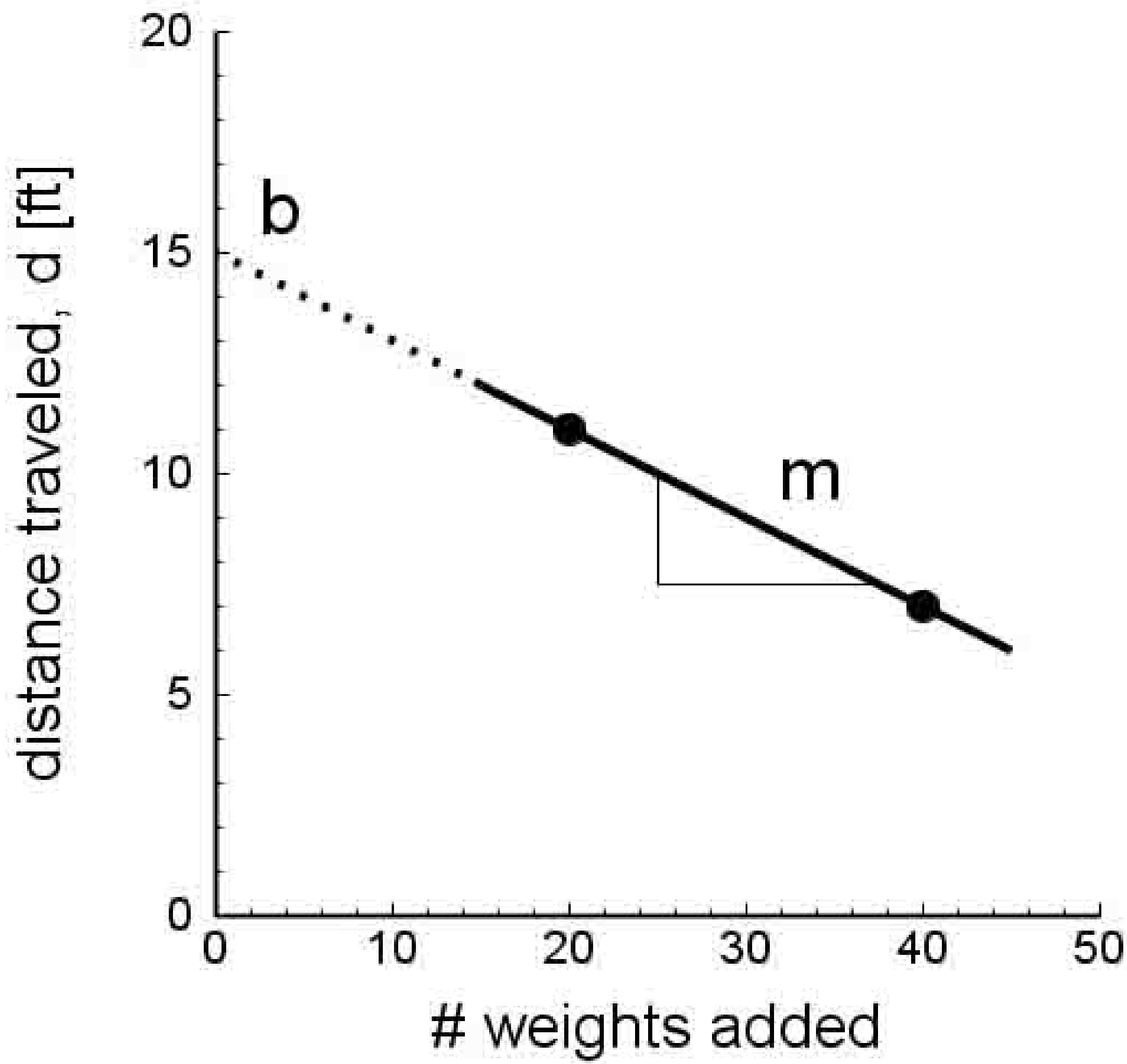
= uncontrolled variations (including accidents and unintended use)

2. EXAMPLE: TWO POINTS = A LINE?

Calibration curve for mousetrap car

based on two tests (points)

“y = mx + b”



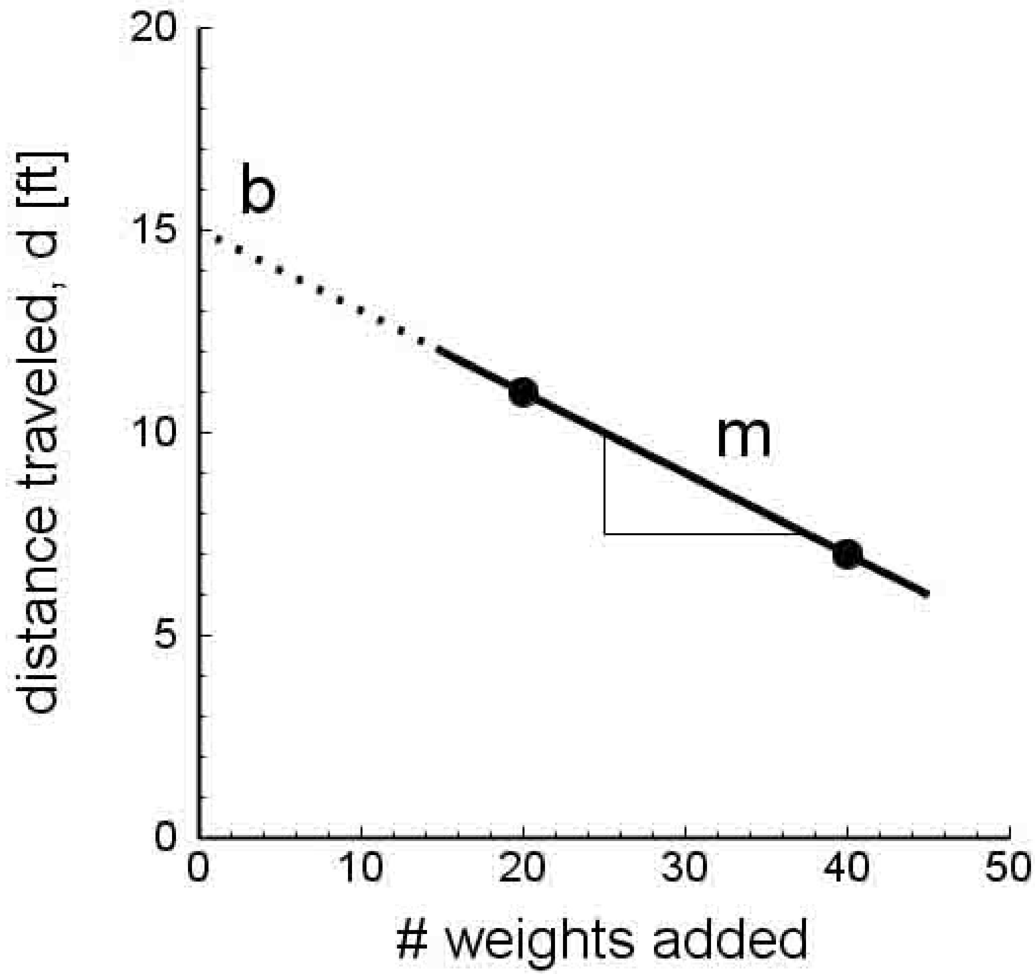
Think like an engineer

Could the true calibration curve be linear?

A. Yes

B. No

C. Not enough information



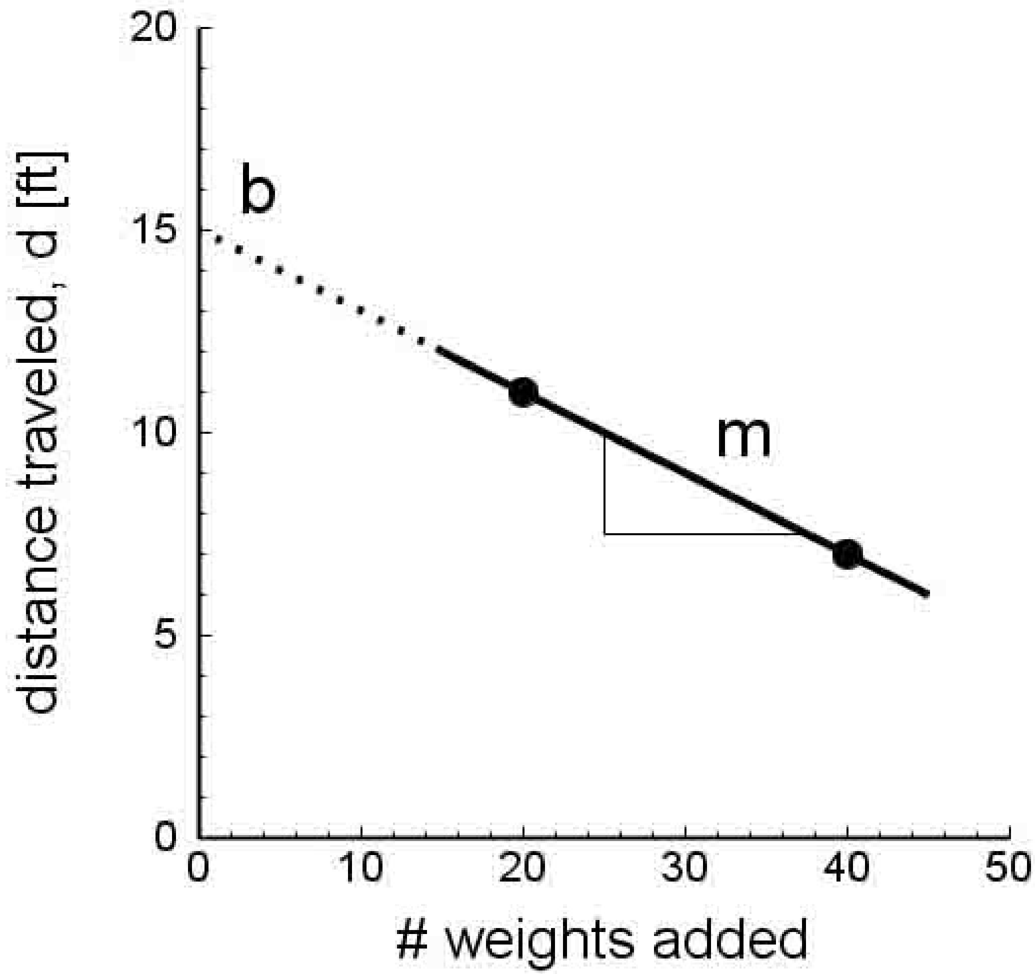
Think like an engineer

Could the true calibration curve be linear?

B. No ✔

weights = 500

⇒ car goes backwards

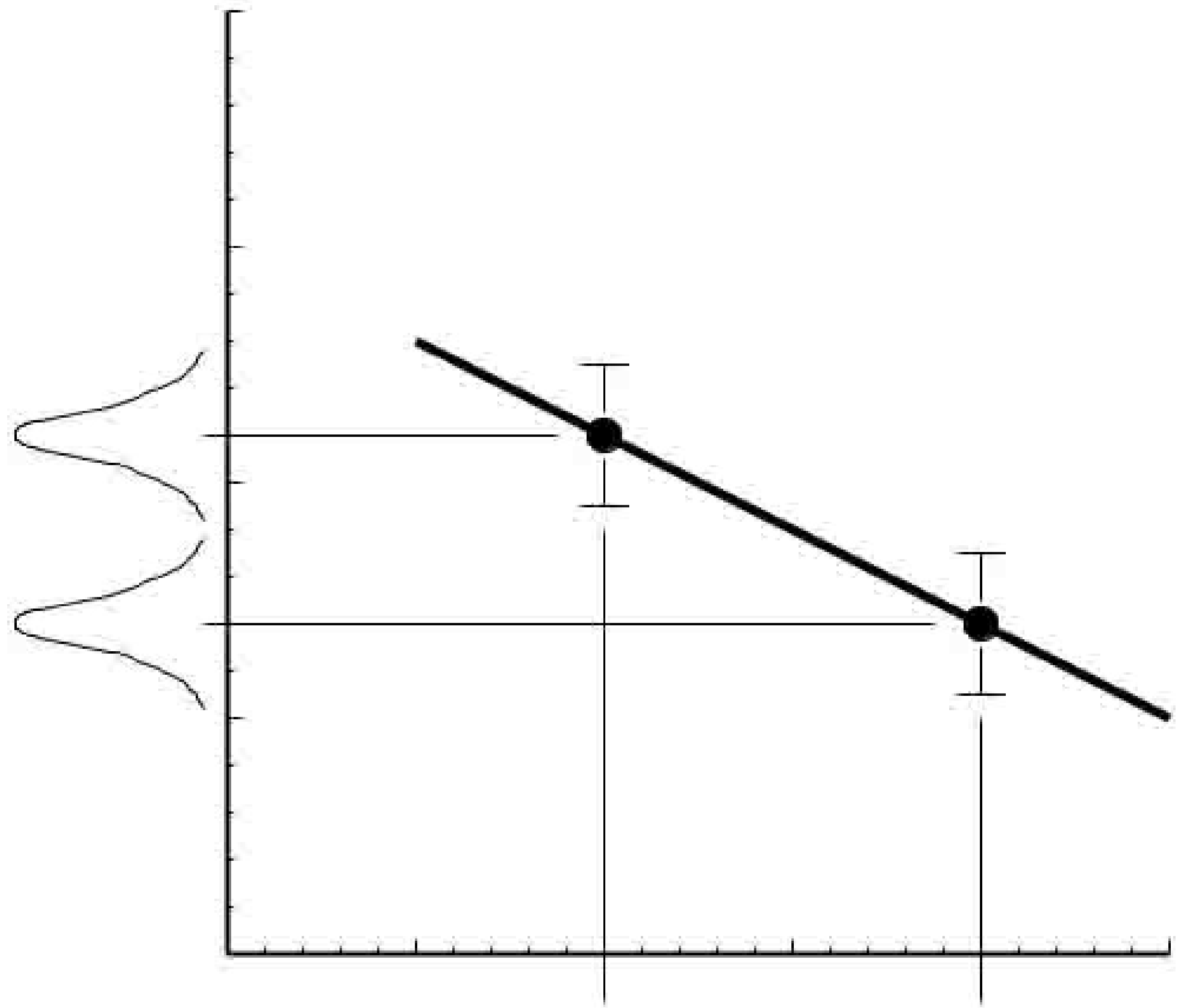


Reality (still two points; piecewise linear)

Repeat the tests with the two weights

There will be variations in the response

Why? *Noise*.



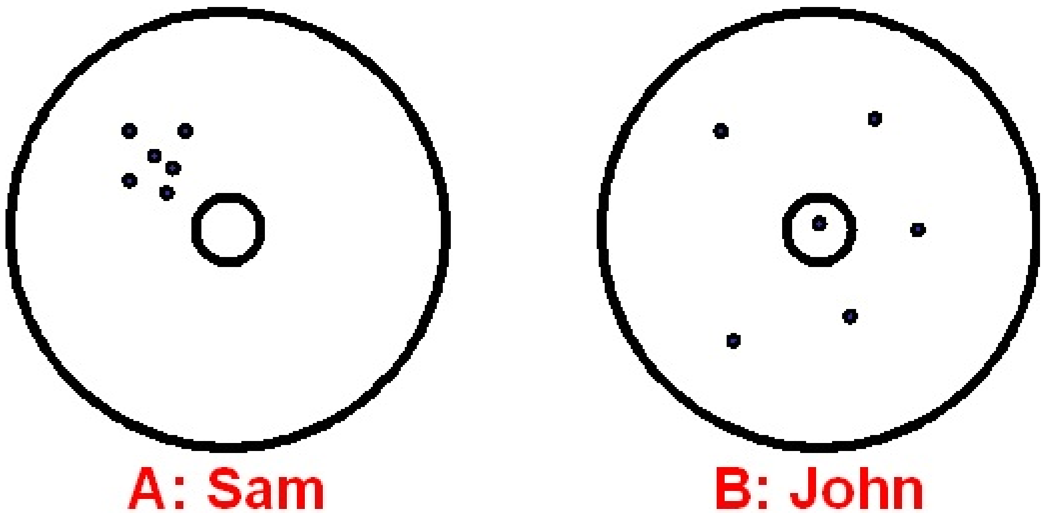
non-ideal conditions = *noise*

- 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?

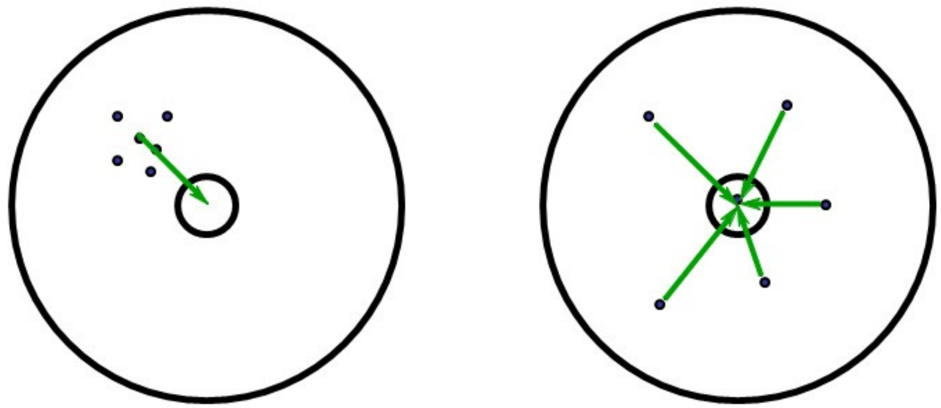
Who is the Better Target Shooter?



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

Who is the Better Target Shooter?

A ✔



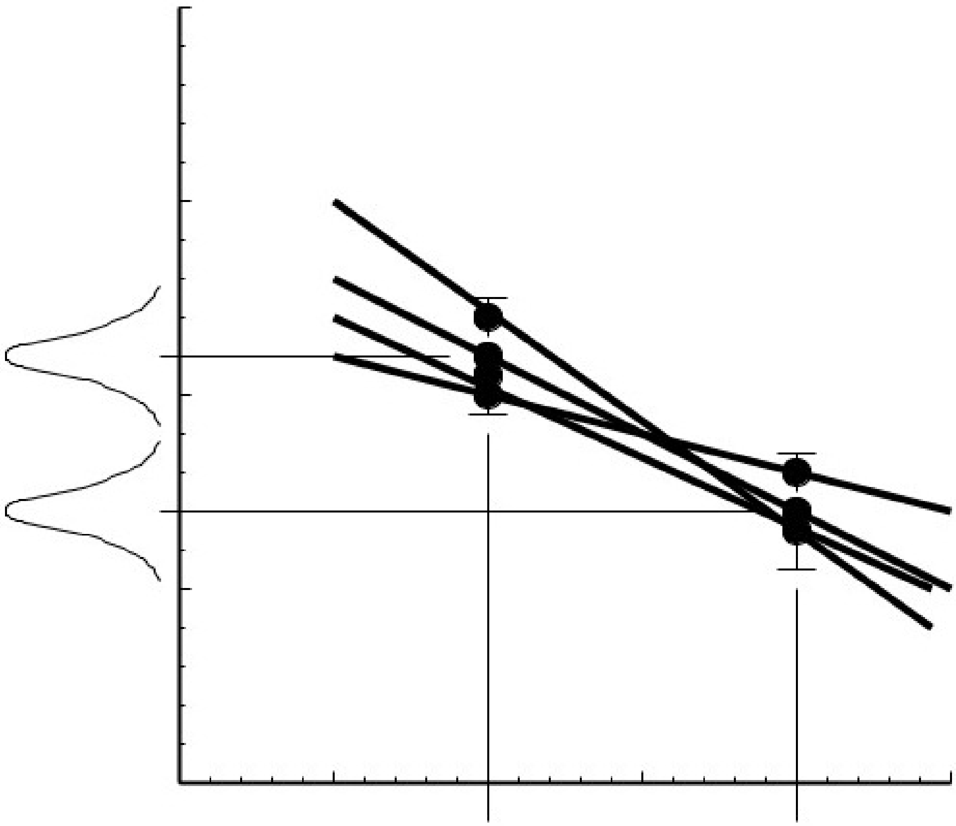
A is better

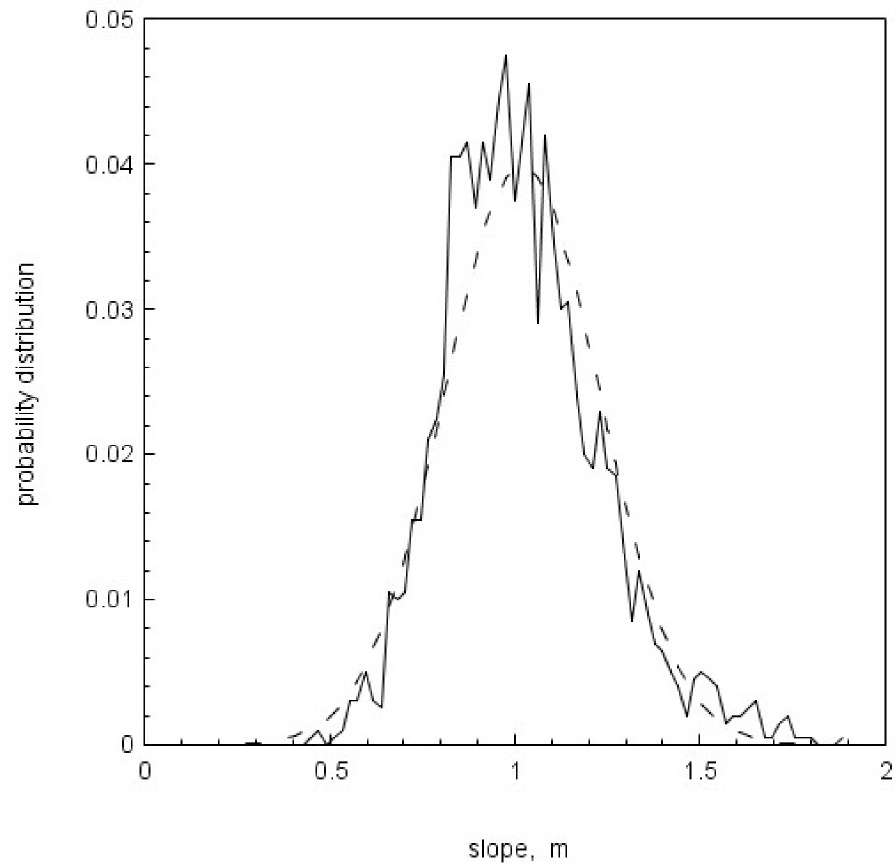
Sam only needs to calibrate better.

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

You calibration curve,

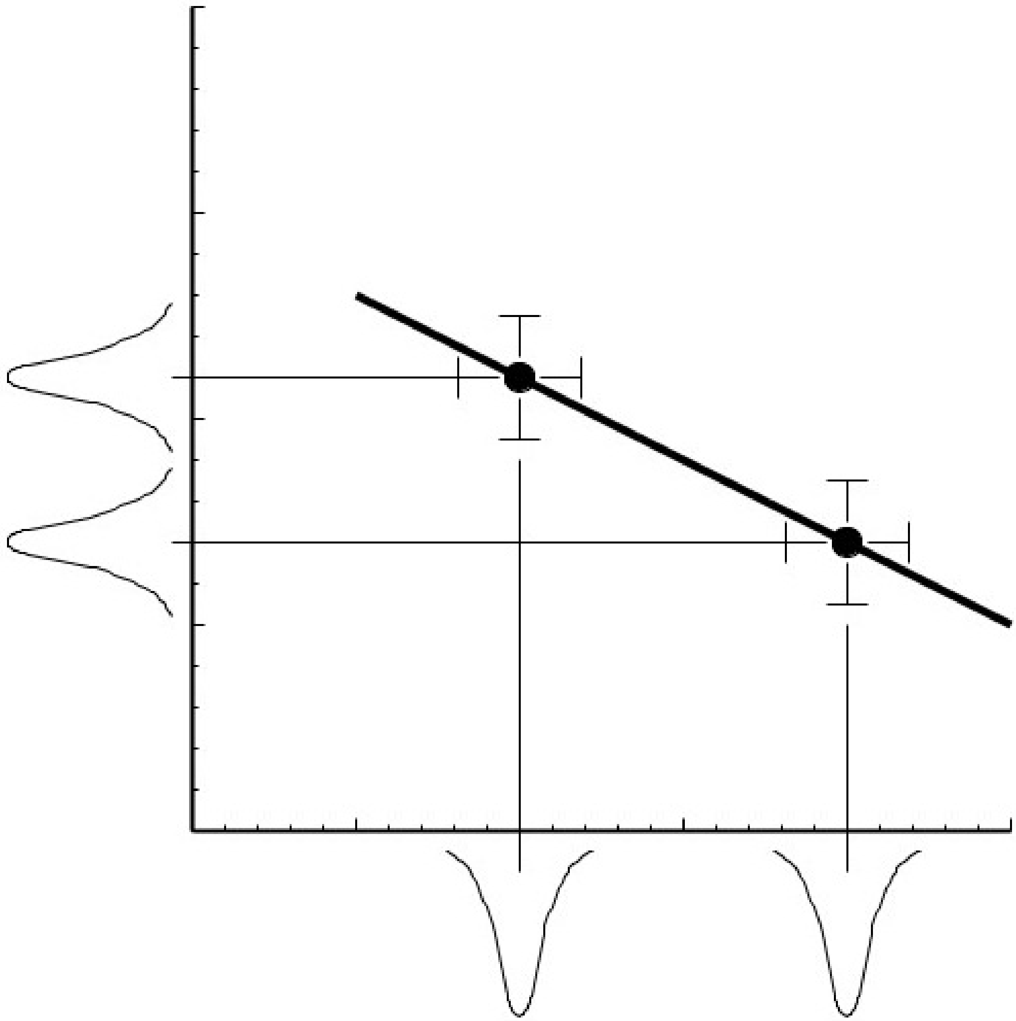
if you only measured the two points once, with noise





You need to find and reduce effect of noise.

What if you input noise into the system?

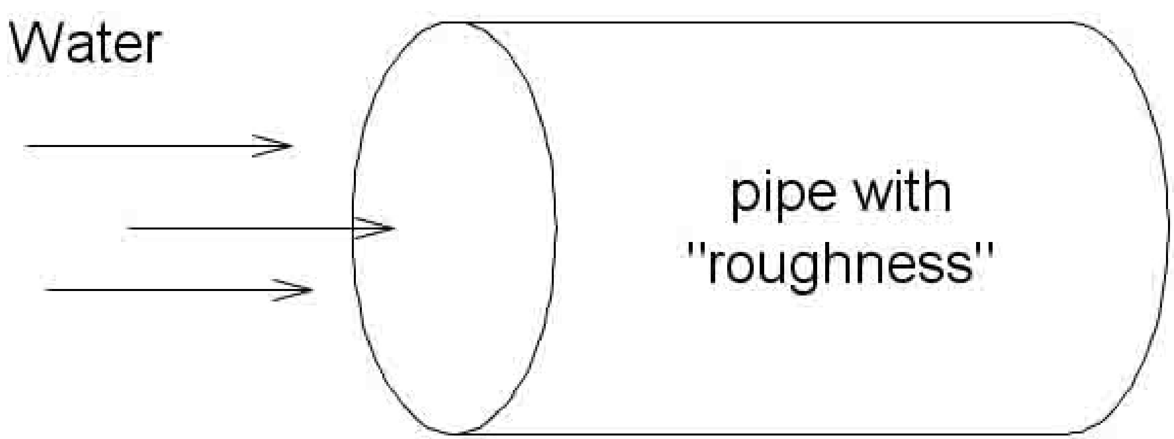


3. EXAMPLE: PIPE FLOW

- you may need a pump

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

- maybe there's roughness in the pipe
  $\Rightarrow$ friction $\Rightarrow$ 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*

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

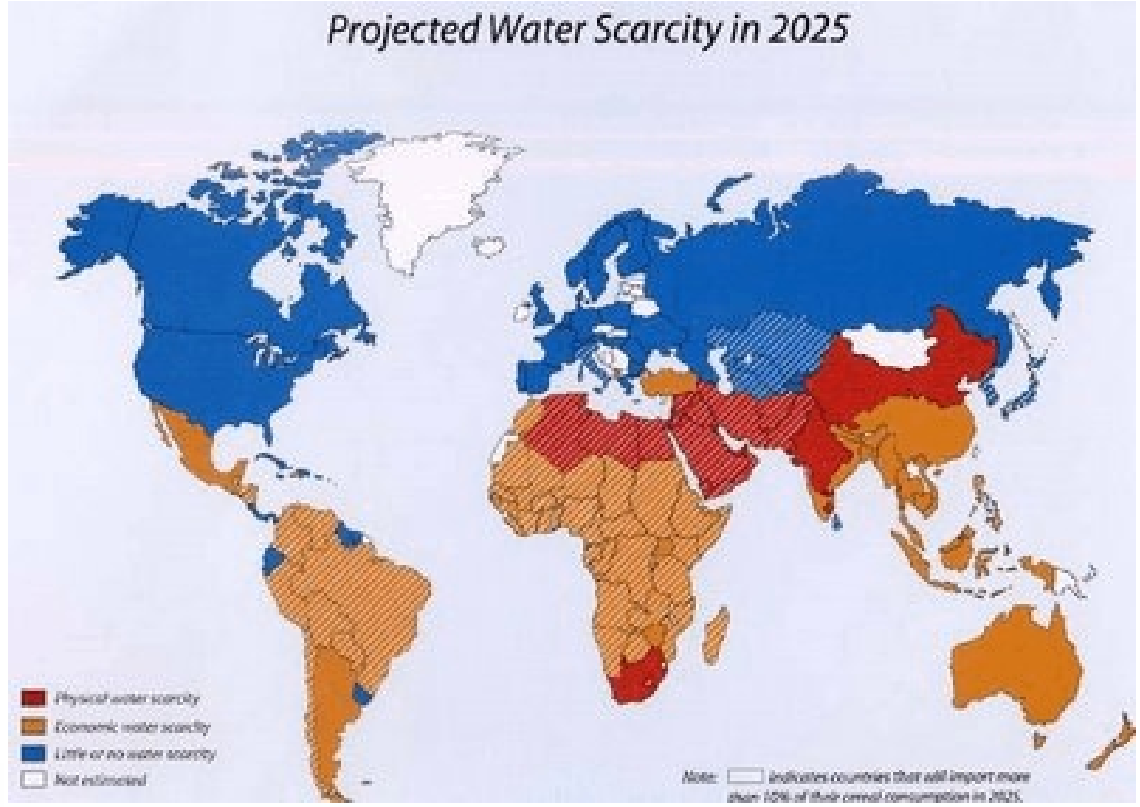
Plug, chug, cobble together, and deploy your amazing engineered water system...

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/m3	water density at 20 deg C				
	mu =	9.85E-004	N.s/m2	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

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

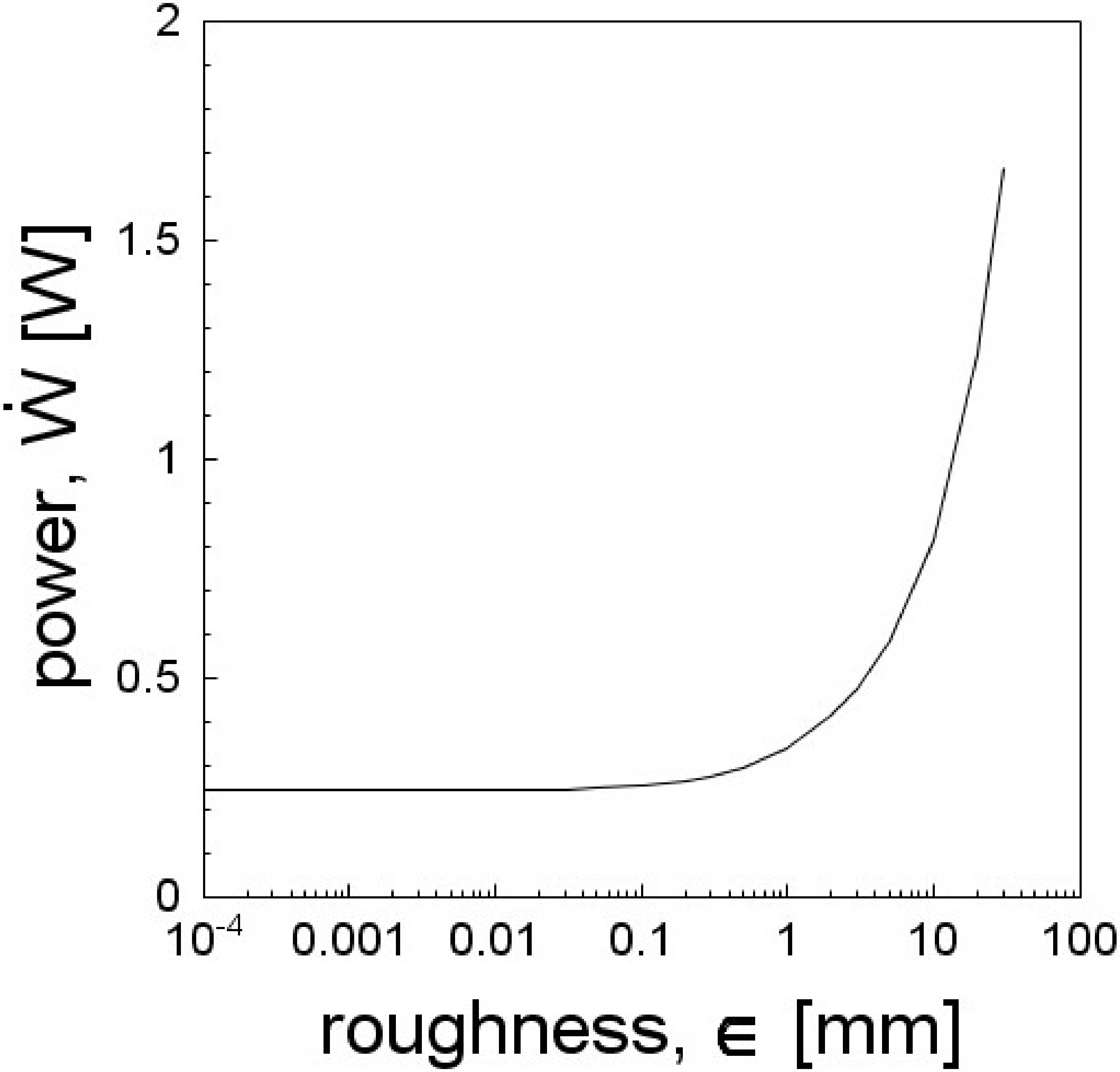
$$\Delta P = f \frac{L}{D} \frac{\rho \mathrm{v}^2}{2}$$

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

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

You can plot this variation,

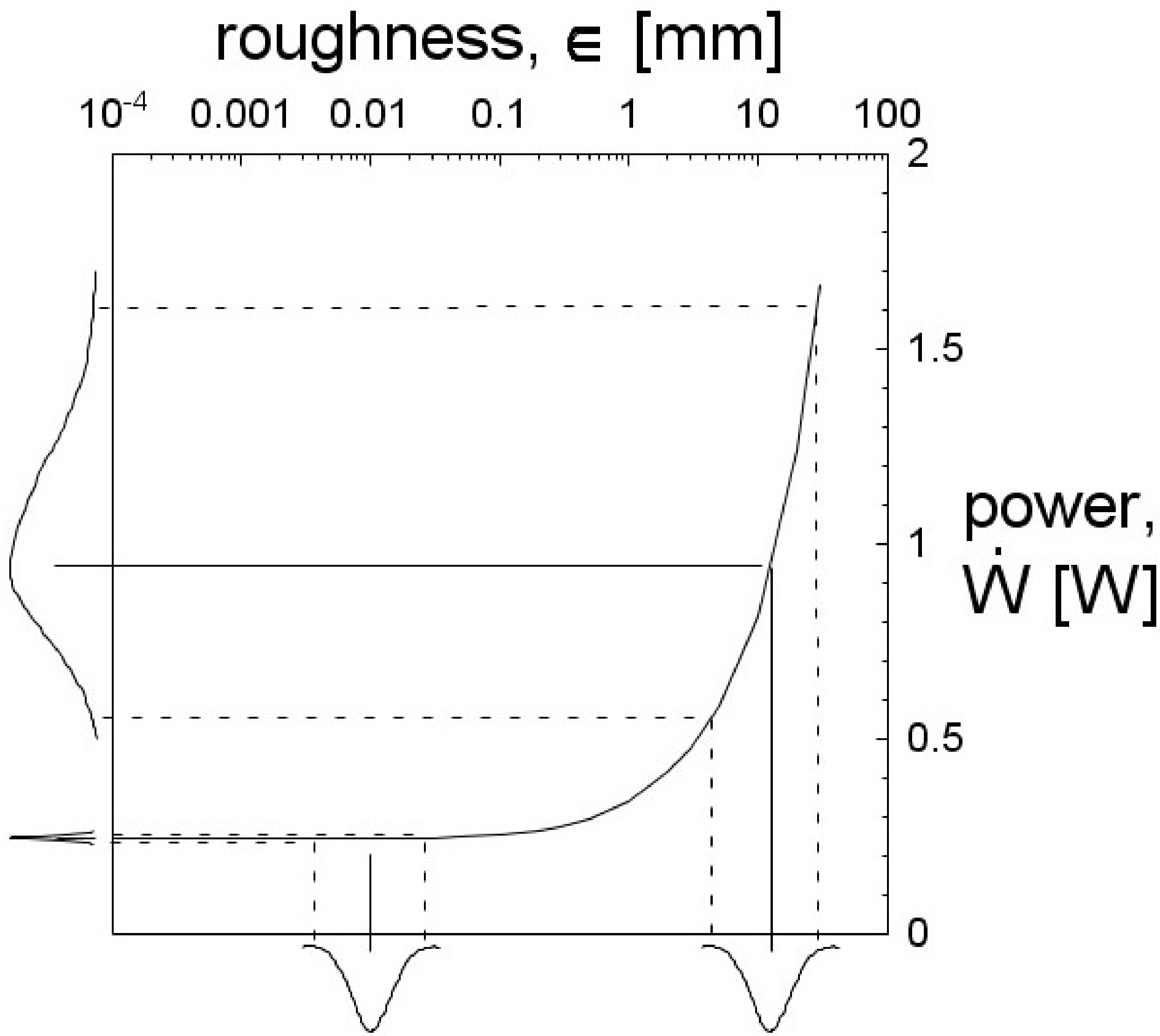
and see something useful



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/m3	water density at 20 deg C				
	mu =	9.85E-004	N.s/m2	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

Oh, sure: that's great...
if you have the equations!

So what if you don't?

The three methods of analysis

– analytical ← limited
– numerical ← expensive
– **experimental** ← 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?

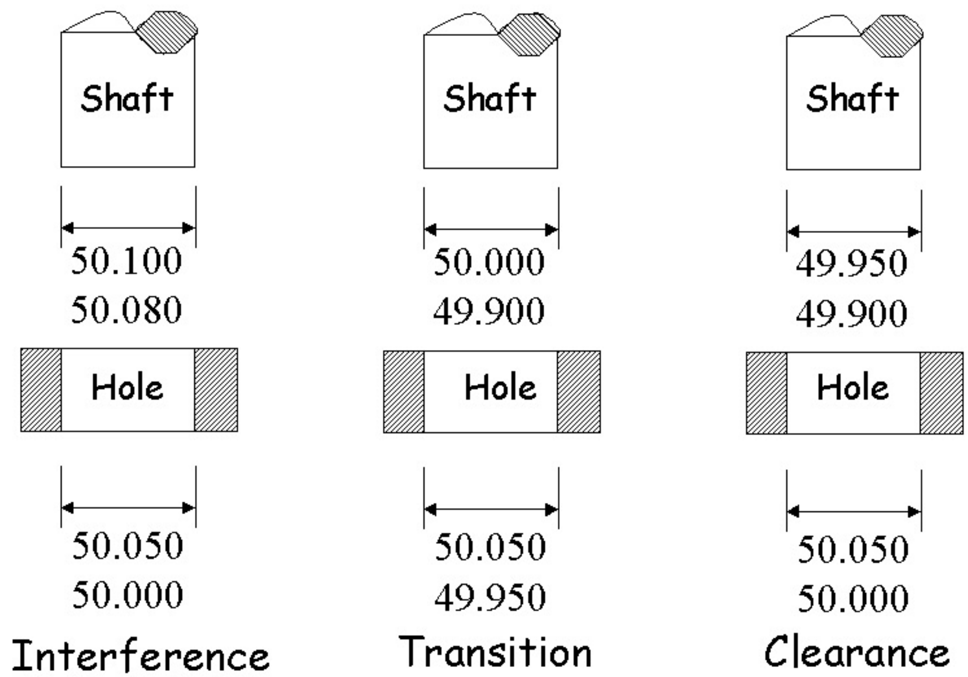
Tolerance Analysis on Decision Matrix

	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: $\quad {}_{\text{shaft}} - \sigma^{-}_{\text{shaft}} \geq {}_{\text{hole}} + \sigma^{+}_{\text{hole}}$

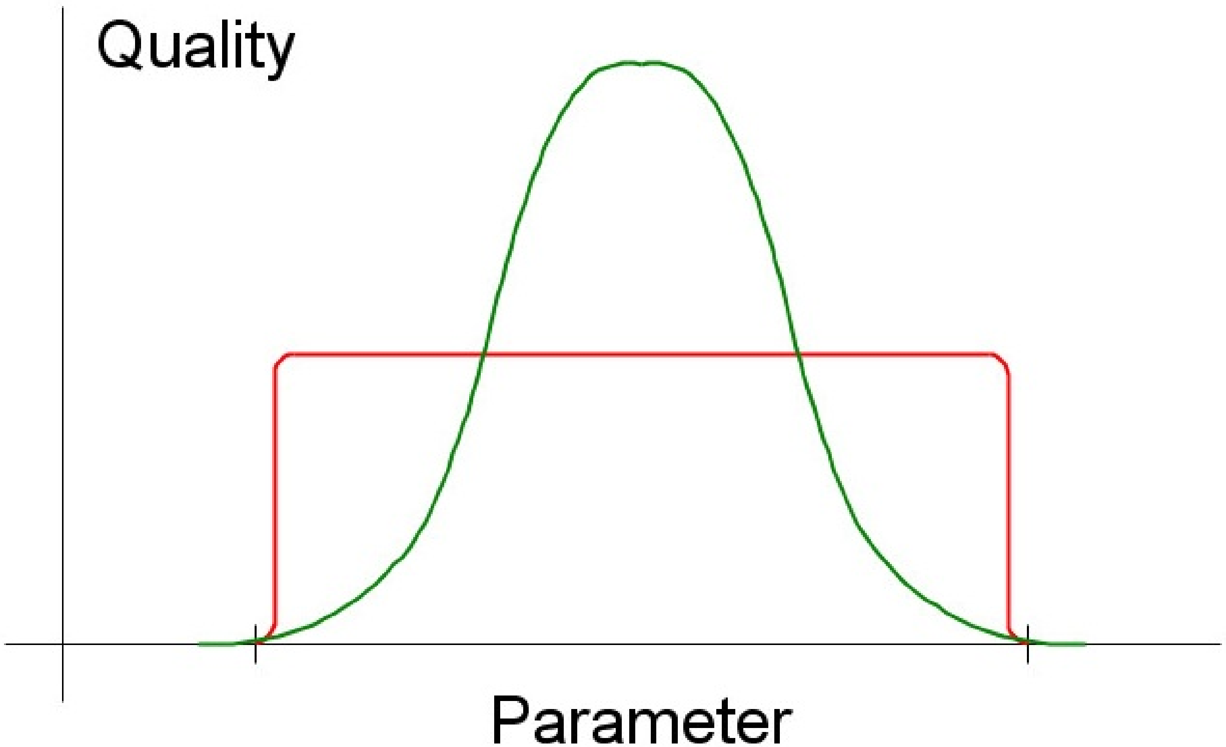
transition fit: $\quad$ in between

clearance fit: $\quad {}_{\text{shaft}} + \sigma^{+}_{\text{shaft}} \leq {}_{\text{hole}} - \sigma^{-}_{\text{hole}}$

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)

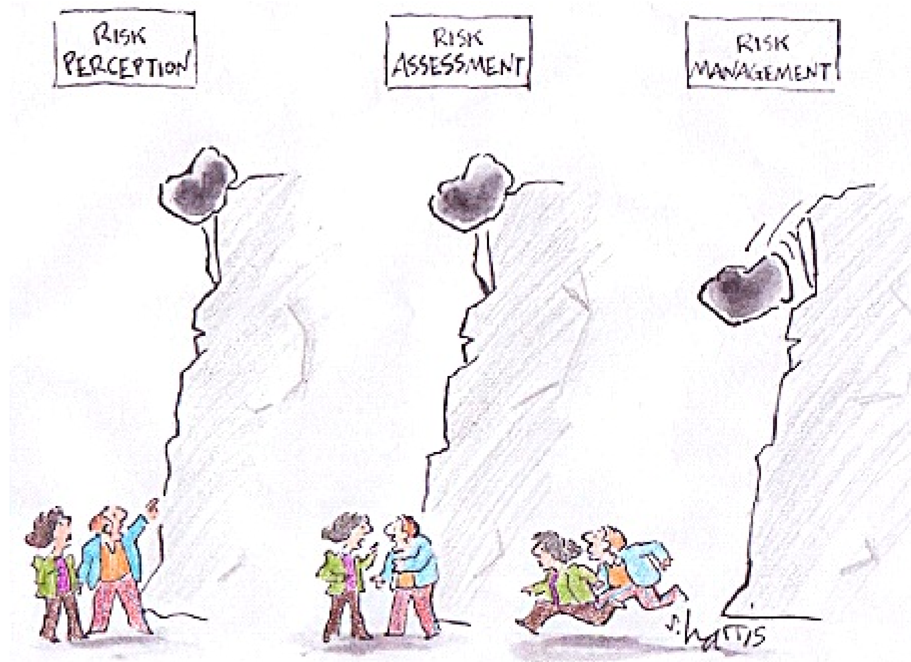
that maximizes quality

in the presence of

functional and environmental noise.

Risk

2. Risk
   - definitions
   - risk perception
   - risk assessment
   - risk management



(With content from Professor Wei Zhou, MANE)

1. DEFINITIONS

ˈrisk [*noun*; from old Italian(?) *riscare* to run into trouble]

– the possibility of incurring misfortune, loss, or injury: PERIL

– something or someone that creates or poses a hazard

Which is safer?

A. Nuclear power

B. Roof-top solar

Which is safer?

A. Nuclear power

B. Roof-top solar

The risk? I start an argument that creates more **heat** than light

More viewpoints:

Take calculated risks. That is quite different from being rash.
– General George Patton

Stupid risks make life worth living.
– Homer Simpson

RISK: there is a risk that all of the oxygen will leave this room.

2. PERCEPTION OF RISK

Lake Nyos in Cameroon. 1,700 fatalities.

The concepts of “risk”

- an unwanted event which may or may not occur
- the cause of an unwanted event which may or may not occur
- the probability of an unwanted event which may or may not occur
- the severity of consequence of an unwanted event which may or may not occur

3. Risk Assessment

The “risk triplet”:

1. What can go wrong?

2. What is the likelihood?

3. What are the consequences?

Typical Observed Error Rates – use of Software

Source of Data	Errors in: Character	Errors in: Field	Distribution of Errors
Inheritance	2-5%	10-25%	50%
Preparation	2%	10%	40%
Transcription	0.06-0.5%	0.3-2.5%	
Entry	0.004%-0.03%	0.02-0.15%	
Software			10%

Software Accuracy (and Confidence)

Comparing calculations based on identical input data	Number of Significant Figures
Single-precision (32 bit) floating point value	7 - 8
Single-precision arithmetic results (approximate)	6
Same code under different computer architecture, operating system, and compiler	4
Same code under continual enhancement	1 - 2
Different codes that do the same thing	1

Examples of Risk Issues for Design Projects

Risk Issues	**Consequences**
– Inaccurate / incomplete CAD models	= System cannot be assembled
– Tasks competing for inadequate funds	= Run out of money
– Parts cannot be found or purchased	
– Tasks competing for inadequate time	= Don't finish on time
– Poor tolerances on system components	= System does not meet specifications

Probability of Occurrence

Estimated by expert judgment or from data drawn from previous experience and events.

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Estimated by expert judgment or from data drawn from previous experience and events.

Question: did you experience delay in your mini-project?

A. Yes
B. No

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Question: did you experience delay in your mini-project?

A. Yes
B. No

Probability of delay ≈ #A's / total polled

$$\text{risk} = \text{severity of the event} \times \text{probability of occurrence}$$

<u>Probability of Occurrence</u>

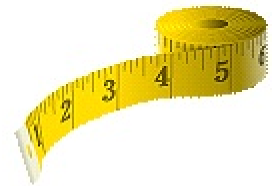
Likely	$\gtrsim$	80% chance
Probably		20 to 80% chance
Unlikely	$\lesssim$	20% chance

<u>Severity of Impact</u>

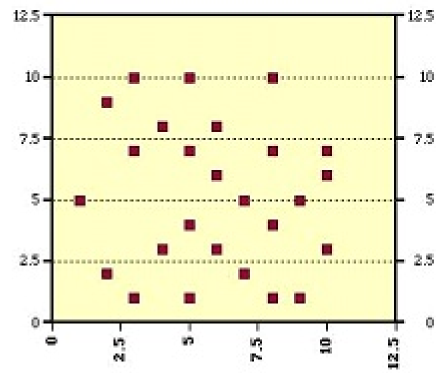
High (5)	–	a major show stopper
Moderate (3)	–	project proceeds forward with impacts on quality, cost and time
Low (1)	–	minor impact on quality, cost and time

Sources of Parameter Uncertainty

- Measurement errors

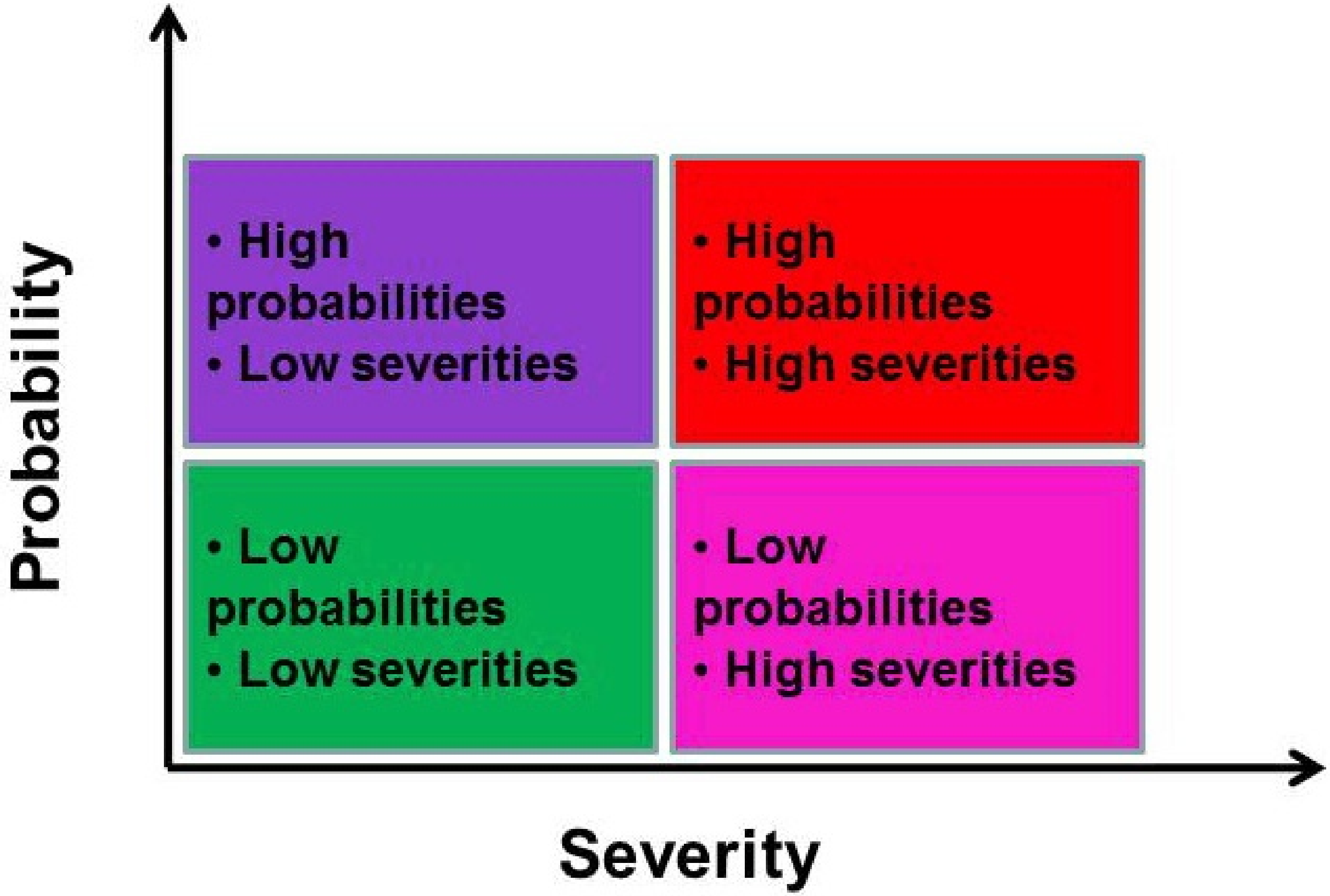


- Systematic errors
- Sampling errors
- Unpredictability
  - – e.g., chaos



- Linguistic imprecision
  - – e.g., using adjectives

Risk Assessment Outcomes



4. MANAGEMENT OF RISK

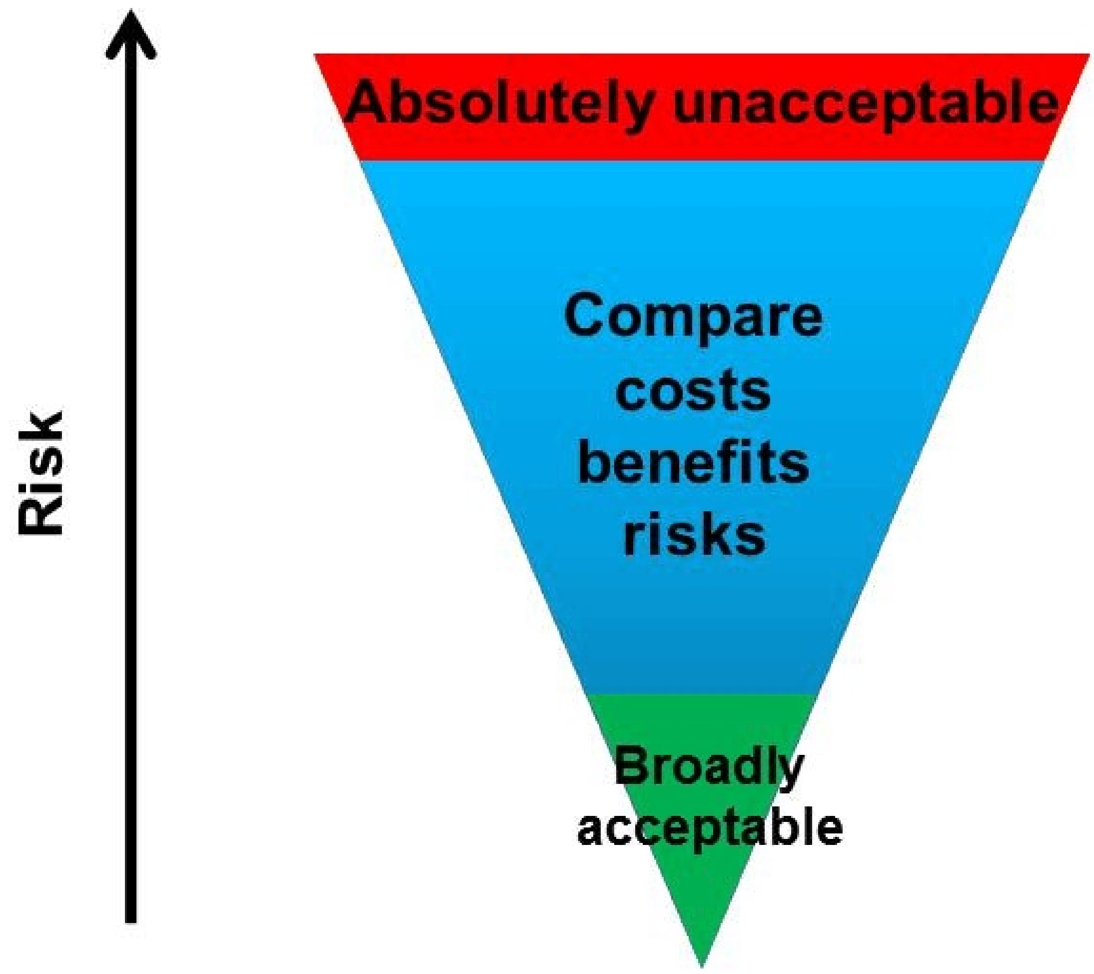
1. What can be done?

2. What options are available and
   what are their associate trade-offs
   (costs / benefits / risks)?

3. What are the impacts of
   current decisions on future options?

Risk Management Options

risk-based decision-making



Your process and product should protect:

- Safety,
- Health, and
- Environment

Project management role

schedule	task prioritization
budget	resource allocation

Time-tested wisdoms:

While solving a problem,
avoid creation of other problems
("Global solutions invite global problems")

Prevention of unwanted events is
cheaper and easier
than dealing with the aftermath