Strategic Problem Solving

Bruce A. Barth
6-Sigma Master Black Belt
Email: theprocessfactor@gmail.com
Cell Phone: 419-704-3666

Speaker Biography:

Bruce Barth is a retired Ford Motor Company 6-Sigma Master Black Belt. He also is a certified Black Belt, Green Belt and Project Champion through Ford. He holds ASQ CSSBB and CQE certifications and is a Shainin Red X Journeyman. Bruce has a BSE in Metallurgy, an MSE in Mechanical Engineering and received extensive applied statistical training as both an undergraduate and graduate student from the University of Michigan. He wrote the current Ford SPS and 6-Sigma Green Belt material and copyrighted them for Ford before retiring. Thank you to Ford Motor Company for granting permission to discuss Strategic Problem Solving in the Webinar.

After retirement, Bruce formed The Process Factor, LLC as a consulting and training development company.   Email: theprocessfactor@gmail.com

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First let's set the Record Straight

- Technical and Transactional Problem Solving is all about the tools, right?
- No, No, No, No, No, No, No, No, No, No!
- So then, it is all about Strategy, Tactics, and Tools applied in that order, right?
- Yes, Yes, Yes, Yes, Yes, Yes!

What is 6-Sigma?

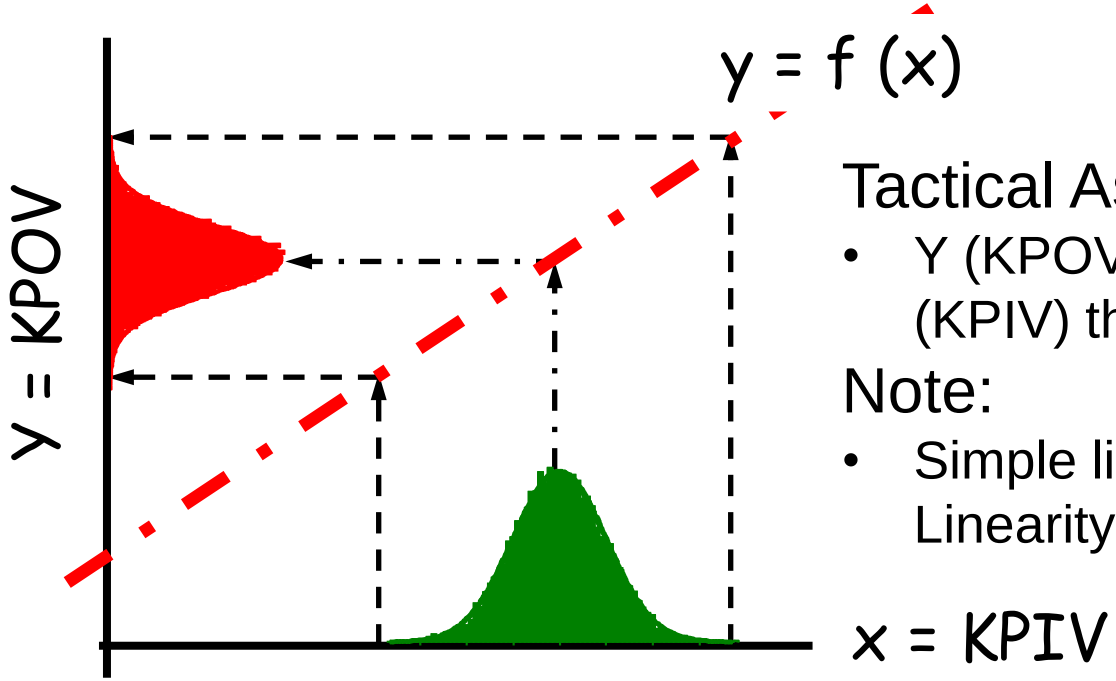
- 6-Sigma is a process of statistical thinking with two principles:
    1. Establish predictability, and,
    2. Reduce variation.
- Statistical thinking, as defined by Dr. W. E. Deming, says that:
    1. Work is interconnected processes,
    2. All processes exhibit variation, and,
    3. Understanding and reducing variation is necessary for process success.

Problem Solving and Quality Control

- Problem solving is not the same as Quality Control.
  - Problem Solving is about predictability and variation reduction.
  - QC is about compliance to standards.
  - You are not limited to QC practices and tools!
- Good strategy and tactics shorten problem solving time-to-solution.
- Most manufacturing problems yield to simple tools. Do not overcomplicate!

Predictability

- Predictability is y = f(x):
  1. It always exists, waiting for us to find it.
  2. It is the physics or physical behavior of a process; How it is supposed to work.



Tactical Assessment:

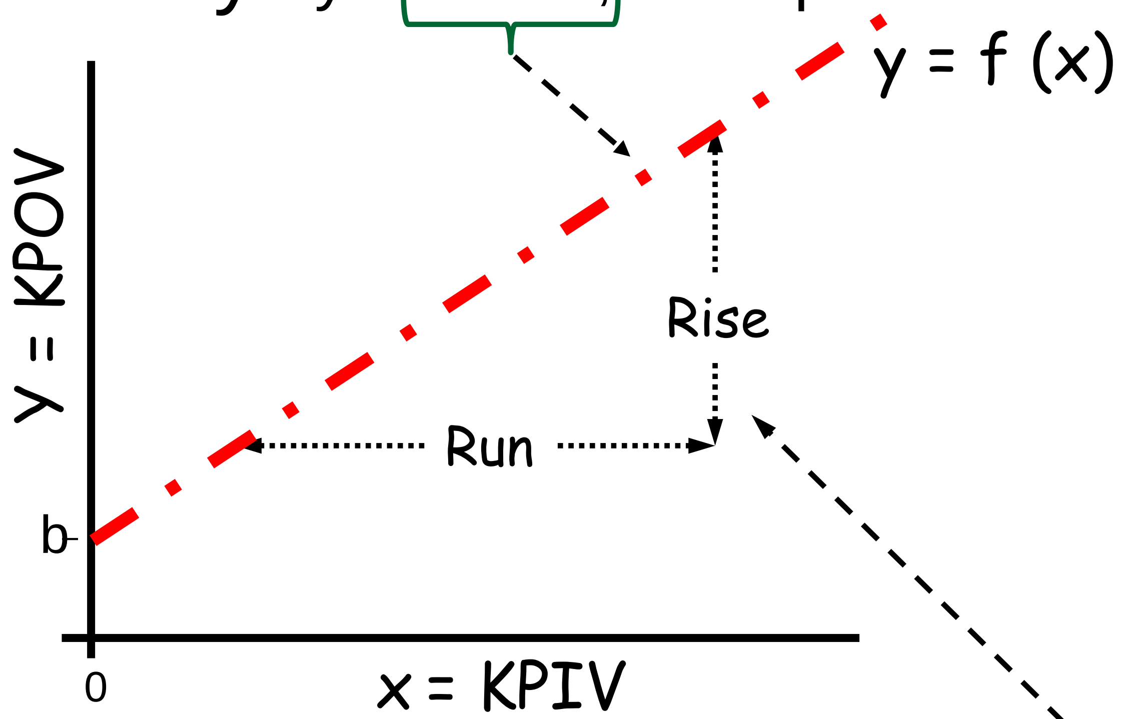
- Y (KPOV) **happens** due to x (KPIV) through the action of f(x).

Note:

- Simple linear example shown. Linearity is not required.

Algebraic Definition of Predictability

1. Predictability: $y = ax + b$, the equation of the line.



y = b at x = 0

2. Factor: x = KPIV

3. Sensitivity: Slope = a = Rise/Run

Sensitivity and Transmitted Variation

- Given the relationship y = f(x), transmitted variation obeys the following equation:

Sensitivity

$$\sigma^2{}_y = \left(\frac{\partial y}{\partial x_1}\right)^2 \sigma^2{}_{x_1} + \dots + \left(\frac{\partial y}{\partial x_n}\right)^2 \sigma^2{}_{x_n} \pm \varphi$$

Variance of y

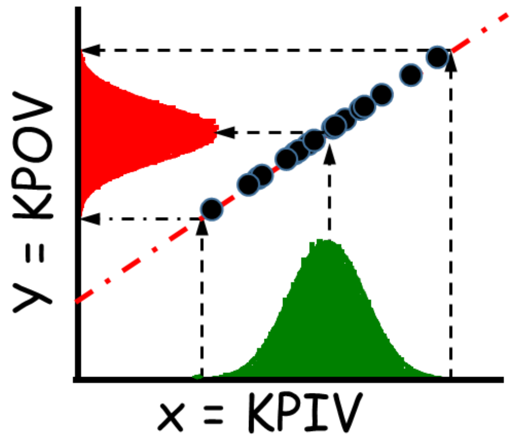
Factor Variance

Error

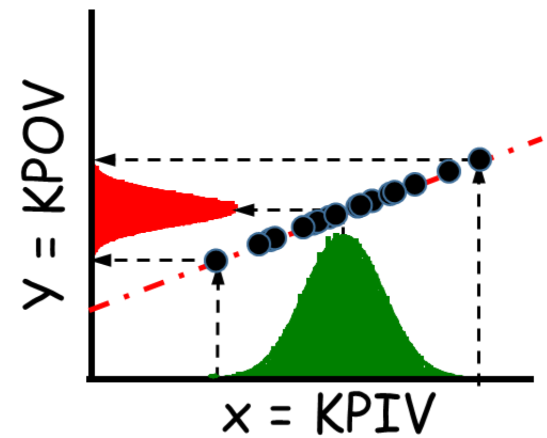
- $\frac{\partial y}{\partial x}$ is the local slope of y = f(x).

Effect of Slope and φ on Variation

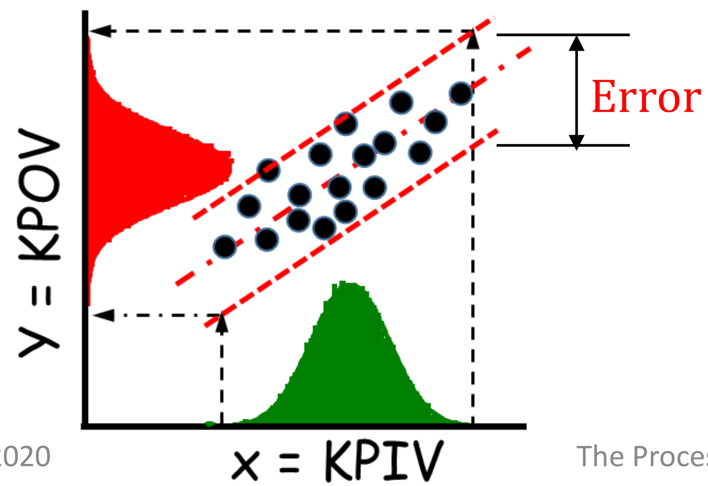
Slope > 0, $\varphi = 0$



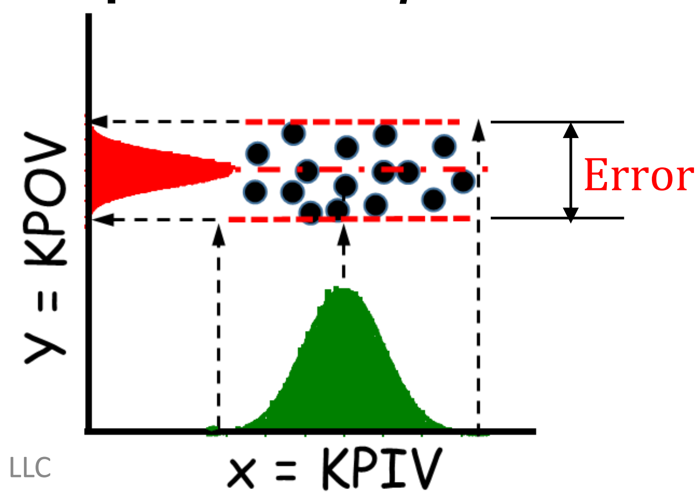
Less Slope, $\varphi = 0$



Slope > 0, $\varphi > 0$



Slope = 0, $\varphi > 0$



Relationship to Problem Solving

- Predictability failure and or excessive variation causes most problems.
- The Solution Chain:
    1. Understand and control predictability
    2. Control variation
    3. Control inputs
- We get to the Solution Chain by:
    1. Strategy, then,
    2. Tactics, and finally,
    3. Tools.

What is Strategy?

- Strategy is the **plan**.
- Strategy is **why** you do something**.**
- Strategies exist at **all** levels.
- Five **key** strategies exist at the problem level that support technical and transactional solution chains.

Strategy first, then Tactics, then Tools

What are Tactics?

- Tactics are **methods** to accomplish the strategy chosen for the solution chain.
- Tactics are **how** you do something.
- Tactics are **procedures** or **processes**.
- Tactics **follow** strategy.

Strategy first, then Tactics, then Tools

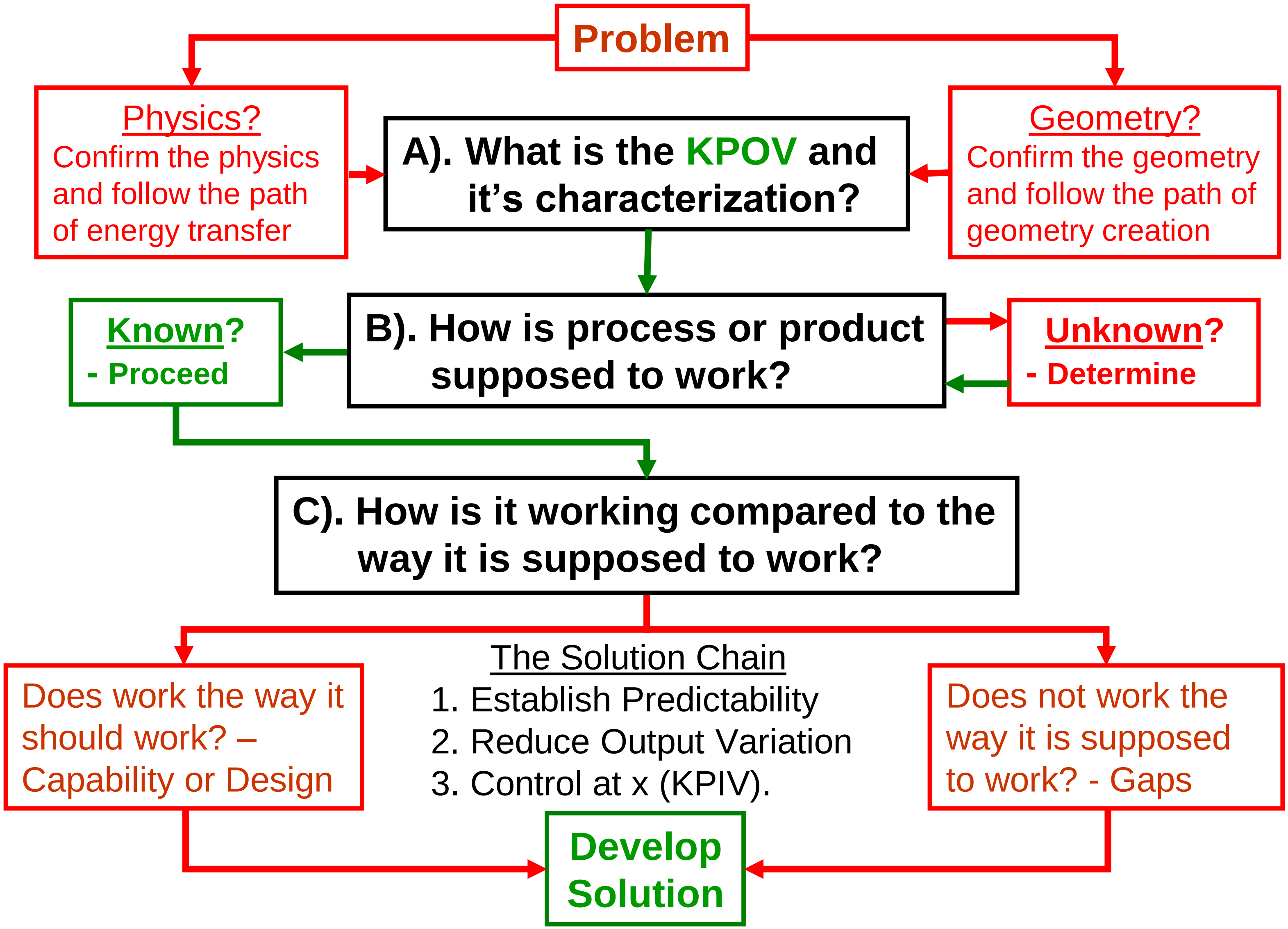
What are Tools?

- Tools are **implements** to execute tactics in support of the strategy.
- Choose the tools only **after** tactical planning.
- Use only the tools **needed** tactically to support the strategy.

Strategy first, then Tactics, then Tools

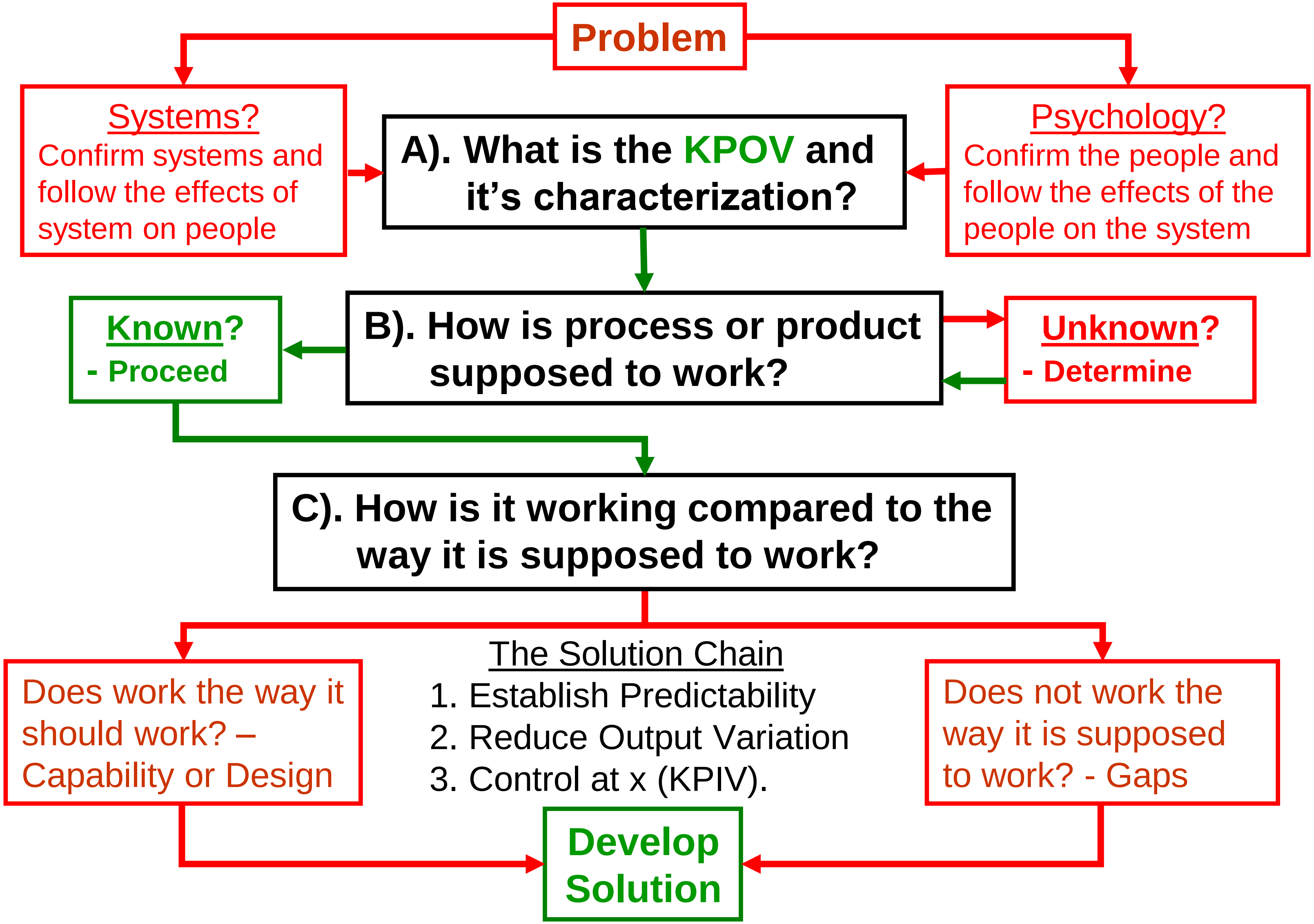
Strategic Problem Solving (SPS)

Technical Model

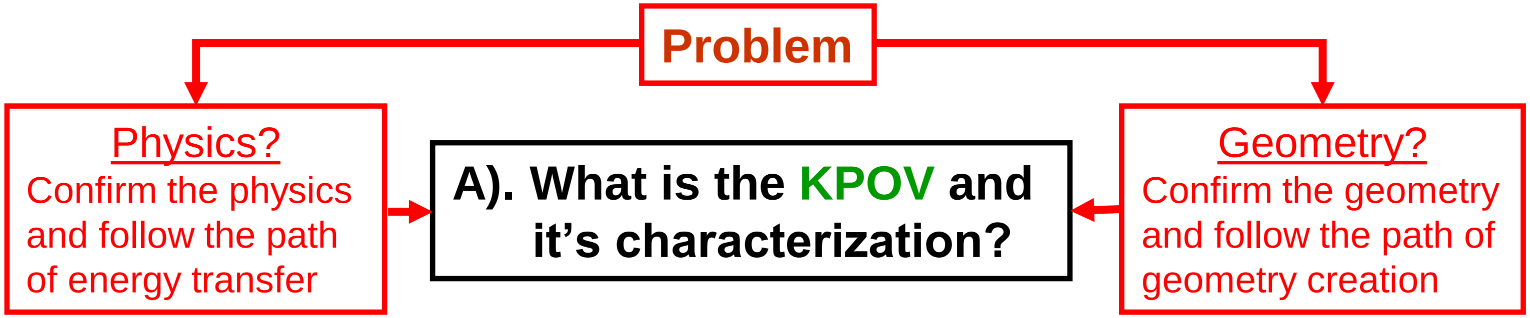


Strategic Problem Solving (SPS)

Transactional Model

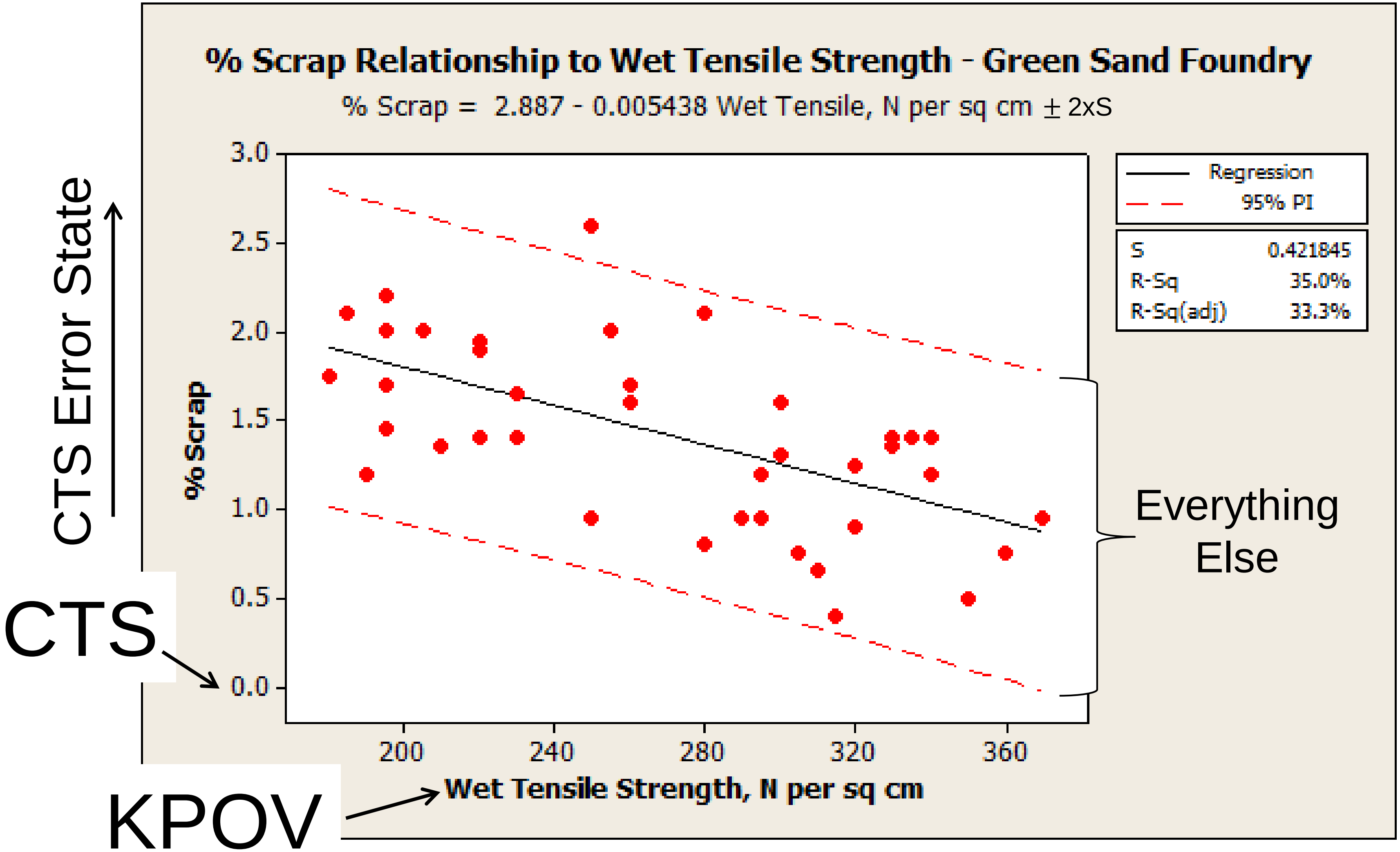


Key Process Output Variable (KPOV)



- Problems: Symptoms affecting customer satisfaction (CTS):
  - Examples: % scrap, warranty, absenteeism, customer satisfaction, % leaks, JPH, etc.
- KPOV: Direct affect on problem:
  - Examples: Diameter, torque, cycle time, time-to-delivery, temperature, pressure, etc.
  - CTS = f(KPOV).

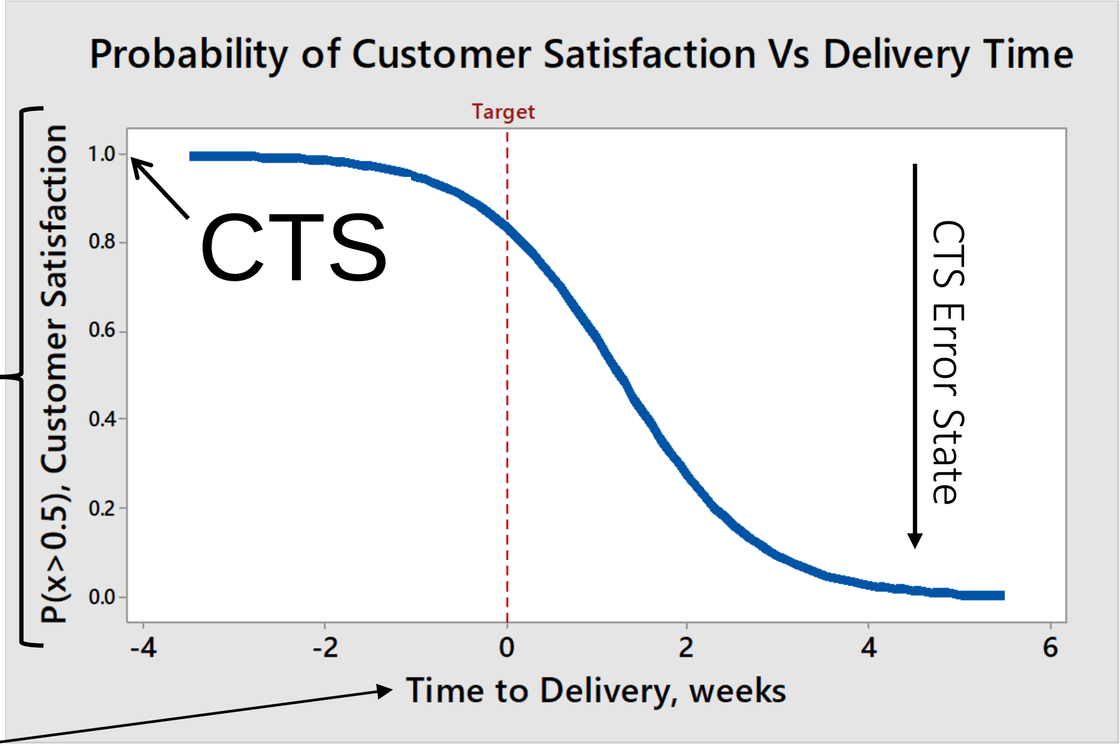
% Scrap Problem and KPOV



Transactional Problem and KPOV

Problem:

- Customer satisfaction with dealer:
  - Measure: Probability of score > 0.5
  - Note: Even 100% dealer satisfaction predicts a re-purchase loyalty of <60%



KPOV:

- Vehicle Time-to-Delivery
  - Measure: Weeks plus or minus promised delivery.
  - Discovered by asking customers why they were dissatisfied.
  - **A KPOV is measureable and actionable**

Technical KPOV Examples

Problem

Physics?
Confirm the physics and follow the path of energy transfer

A). What is the KPOV and it's characterization?

Geometry?
Confirm the geometry and follow the path of geometry creation

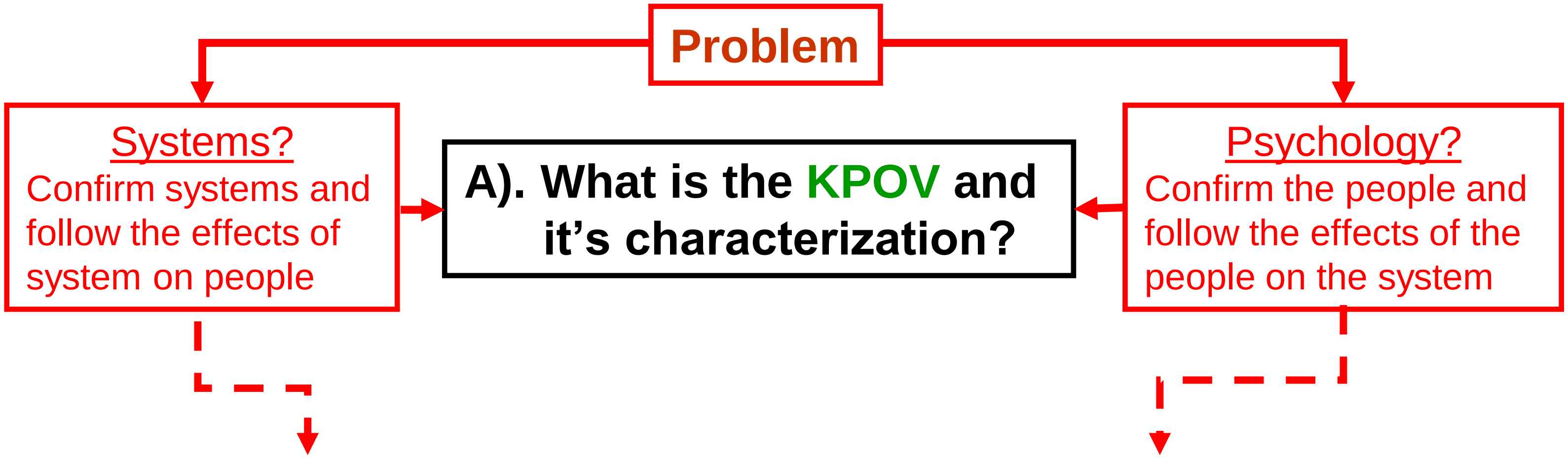
Physics KPOV Examples

- Tensile Strength
- Leak Rate
- Burst Strength
- Flow Rate
- Rate of Vaporization
- Others

Geometry KPOV Examples

- Diameter, Radius
- Length, Width, Height
- Gap, Paths, Porosity
- Flatness, Roundness
- Circularity, Concentricity
- Others

Transactional KPOV Examples



System KPOV Examples

- Automatic stock trading.
- Computer assisted call count solicitation.
- Auto texting accuracy
- AI process controls
- Others

Psychology KPOV Examples

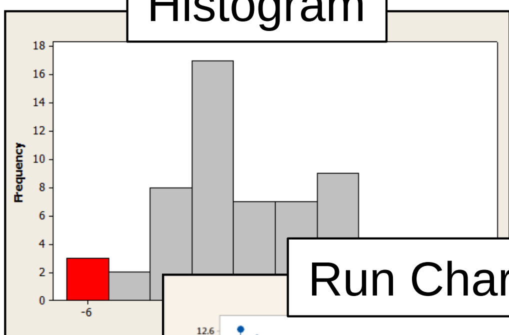
- Time-to-delivery delays
- Human error
- Human cycle time delays
- Measurement mistakes
- Process interference
- Others

KPOV Characterization

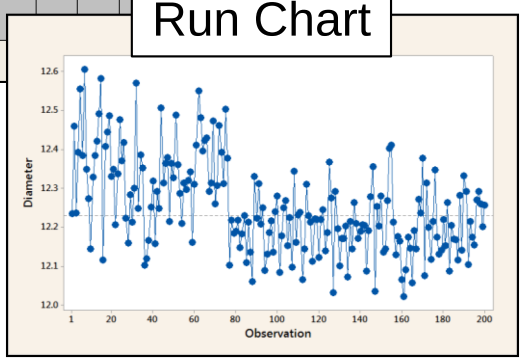
- KPOV characterization examines the whole range of variation for contrasts.
- Characterization tools examples:

Variable Data

Histogram

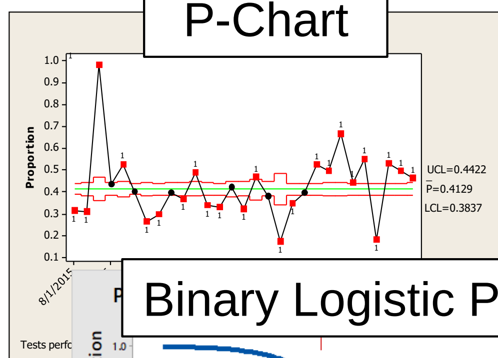


Run Chart

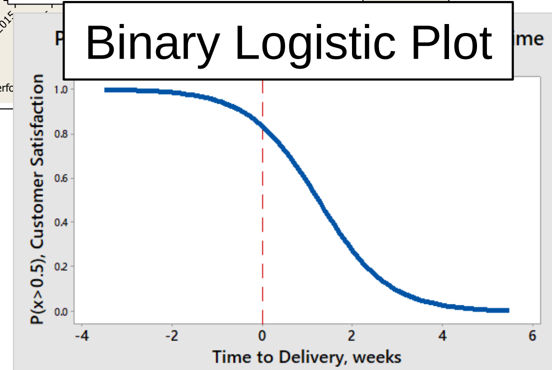


Attribute Data

P-Chart



Binary Logistic Plot



Others

- Probability plots
- Concentration diagrams
- Dot plots
- Box plots
- Etc.

Objective

Tell us about the KPOV in terms that guide us to useful contrasts

Determining “How it is meant to work”

B). How is process or product supposed to work?

Known? - Proceed

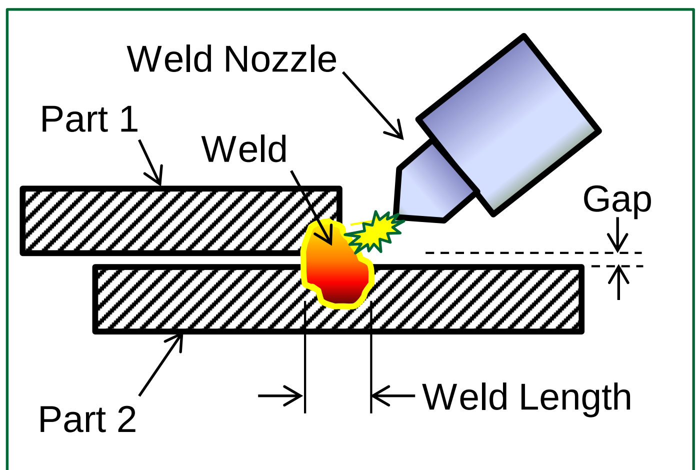
Unknown? - Determine

Frequently Used Tools

- Physics
- Process Flow Chart
- Boundary and Function Flow
- Scatter Plot
- Physical Diagrams
- Free Body Diagrams
- Transfer Functions
- Design of Experiments
- Regression
- Subject Matter Experts

Physical Diagram Example

- KPOV = Weld Strength.
- Weld strength correlates to weld length, so, we can let KPOV = Weld Length.
- This is a surrogate KPOV



Potential KPIV Factors

- Torch Angle
- Amperage
- Wire Feed Rate
- Gap between parts
- Torch Speed
- Weld Spatter on Nozzle

Testing "How it is working"

Does work the way it should work? – Capability or Design

<u>The Solution Chain</u>

1. Establish Predictability
2. Reduce Output Variation
3. Control at x (KPIV).

Does not work the way it is supposed to work? - Gaps

Develop Solution

<u>Example</u>

- Process plan: No need to replace weld nozzles in use.
- Action: Per plan, nozzles not replaced in use but they actually get contaminated.
- Contaminated nozzles cause porosity.

<u>Example</u>

- Process plan: Replace nozzles every 100 cycles.
- Action: Not replacing the nozzles in use. Caused nozzle contamination.
- Contaminated nozzles cause porosity.

Five Key Strategies

Working backwards from y to x

y → x

KPOV → KPIV

Always use y (KPOV) to lead to x (KPIV).

Transfer function Physics

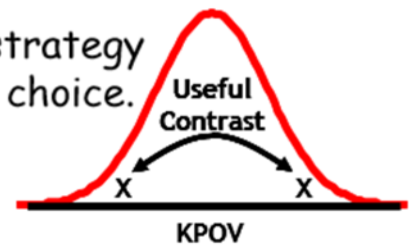
y = f (x)

KPOV = f (KPIV)

All processes have a transfer function. Find it!

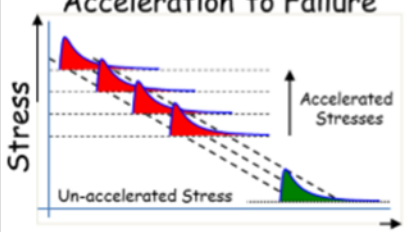
Contrast and Convergence

A strategy of choice.



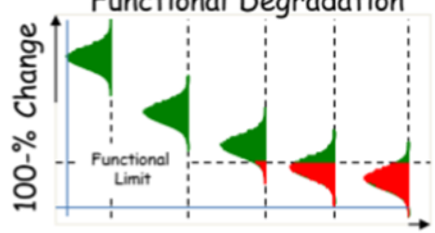
Acceleration to failure or degradation

Acceleration to Failure



Time to Failure, Log (T)

Functional Degradation



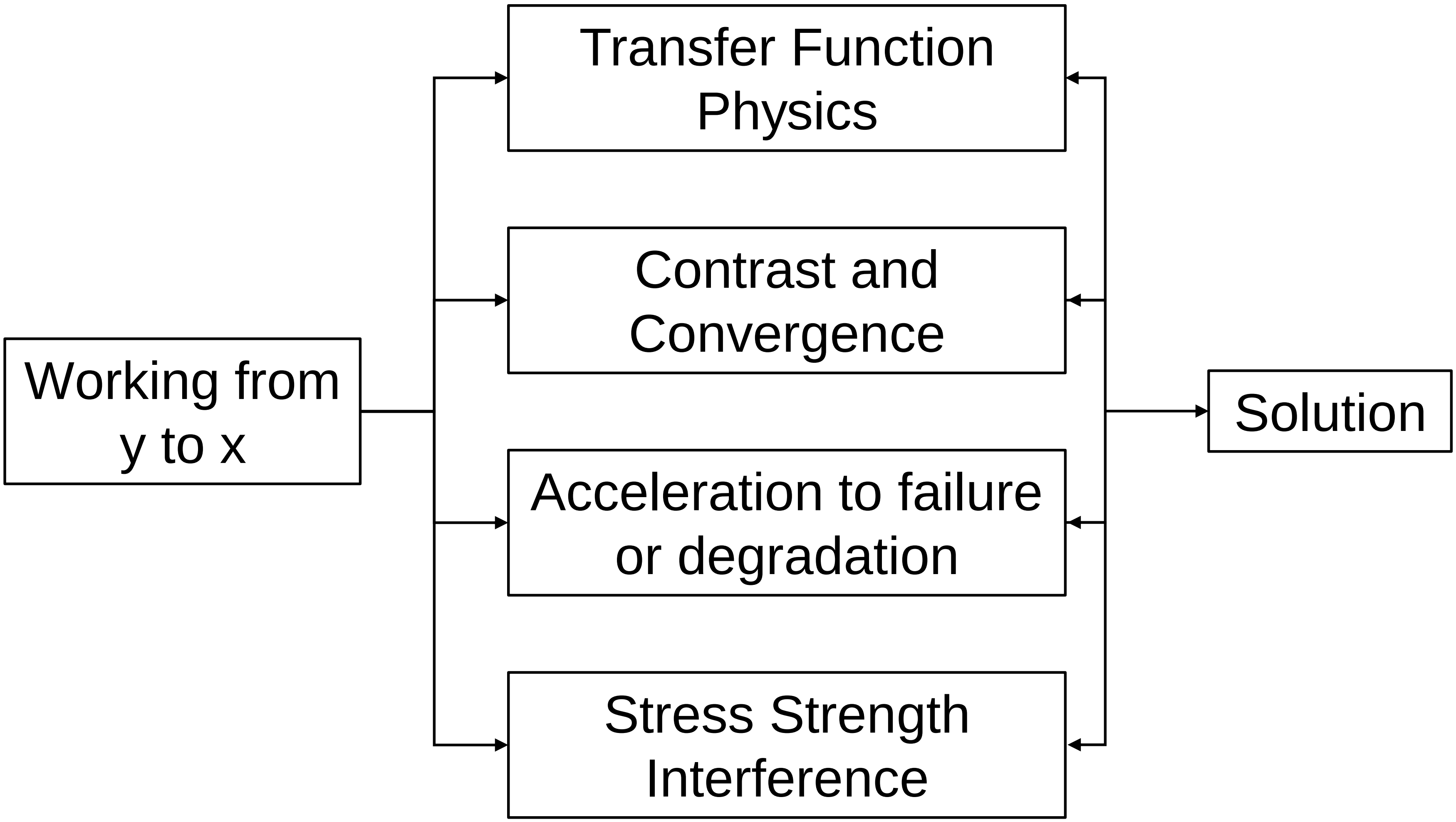
Test Time at Constant Stress

For rare or difficult events

Stress Strength Interference

Why things break

Five Strategies Hierarchy



The Hierarchy – Always work y to x

Working backwards from y to x

y → x

KPOV → KPIV

Always use y (KPOV) to lead to x (KPIV).

Working Backwards from y to x

- Working y to x is a key to **efficiency:**
  - Characterize the y (KPOV) before considering x.
  - Proceed y to x to reduce combination complexity.
- Working x to y is **inefficient:**
  - Too many empirical combinations of x exist for random convergence on y:
    - e.g. 20 candidates for x makes over 1 million combinations (minimum).
- **Always** use y to guide you to x!

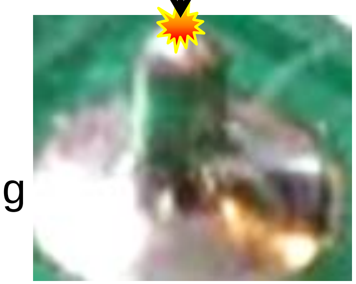
Warranty Problem – Radio not working

Tactical Assessment

- Four circuit boards per radio.
- 10,000 components in circuits per radio.
- Problem not obvious, solution strategy needed

Solution Strategy: y to x

- Test for power: Swapped the power circuit board with a working radio. The original radio now worked, the other not working. Problem lives in power board.
- Autopsy: Circuit continuity found broken at a cracked solder joint.
- Manufacturing process flow: Observed the soldering tip pushing sideways in operation causing the crack. KPOV = Force
- Corrected soldering tip, problem solved!



- No force
- No bending
- No crack

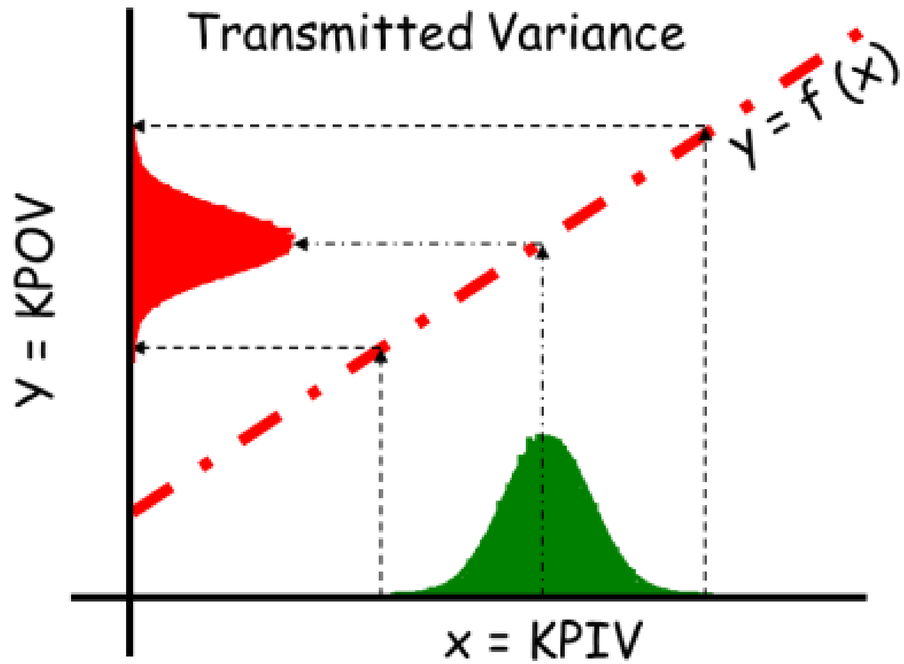
Hierarchy – Transfer Functions

Transfer function
Physics

y = f (x)

KPOV = f (KPIV)

All processes have a transfer function. Find it!



y = f(x) is an equation of relationship.

- y = ax +b is the equation of y = f(x) above where a = slope and b = intercept at x = 0.

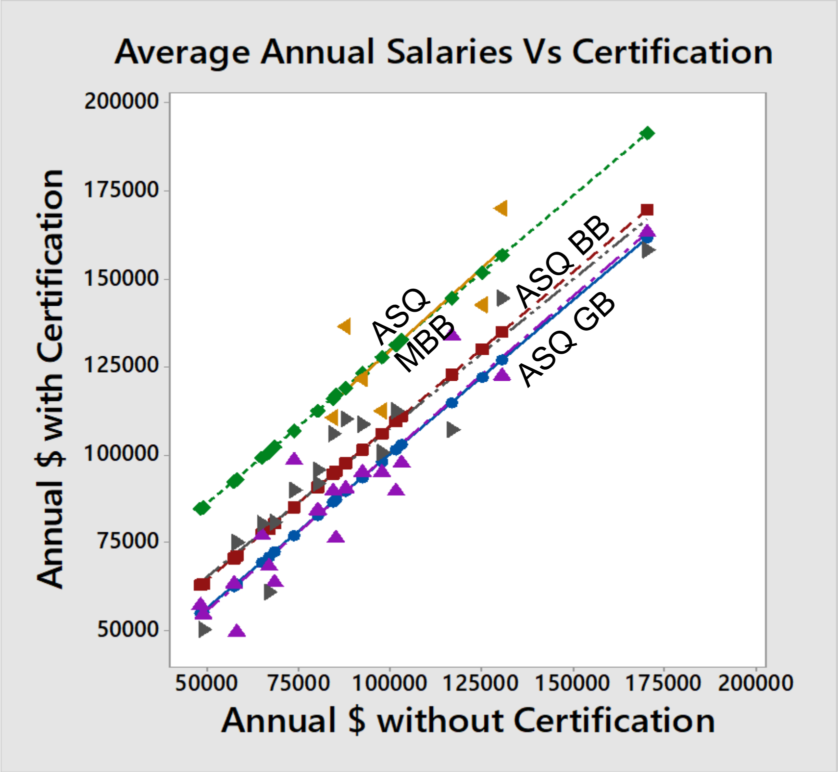
Transfer Function Physics, $y = f(x)$

- **ALL** projects have a Transfer Function:
  - First principle **Physics** models: e.g. CAE. Physics models are universally transferable.
  - Inference space **Empirical** models: e.g. DoE. Results limited to the inference space.
  - A **Hybrid** of physics and empirical models: e.g. If a model does not confirm but the physics are OK, it is adjusted empirically for use. This sets up a path to finding the physics while making the model immediately useful.
- Transfer Functions define **predictability**!

Labor Relations – Salary Planning

Tactical Assessment:

- ASQ surveyed the salaries of certified US 6-Sigma personnel in 2016.
- KPOV = Salary with Certifications, $.
- KPIV = Salary without Certifications.



Solution Strategy: TF

- Scatter Plot: Used ASQ survey data and regression to make salary Transfer Functions.
- VOP: Data correlation confirmed with 88% R-sq. (predicted).

Empirical Transfer Functions

ASQ MBB Certification:

Salary, $ = 42080 + (0.8750 x $ No Certification) $\pm$19870 (95% confidence)

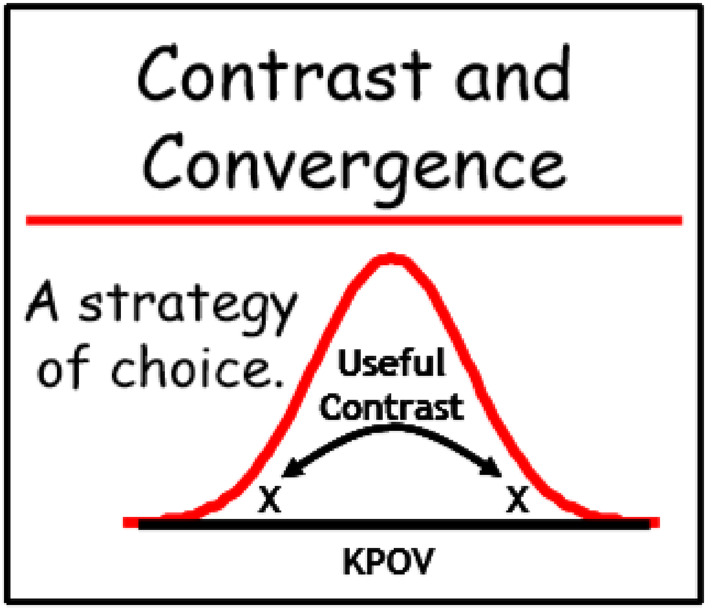
ASQ BB Certification:

Salary, $ = 20346 + (0.8750 x $ No Certification) $\pm$19870 (95% confidence)

ASQ GB Certification:

Salary, $ = 12337 + (0.8750 x $ No Certification) $\pm$19870 (95% confidence)

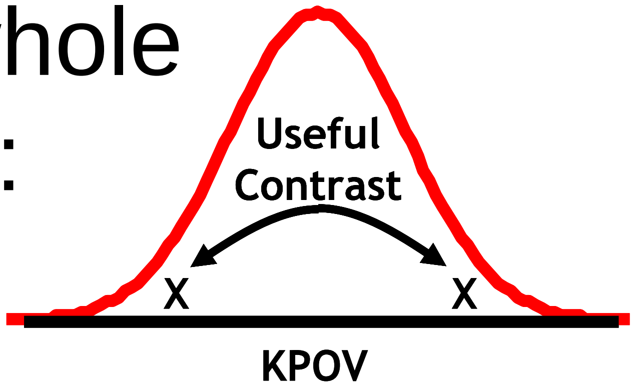
Hierarchy – Contrast and Convergence



Find the distribution extremes and study the useful contrast.

Contrast and Convergence

- Based on knowing the whole range of KPOV variation:

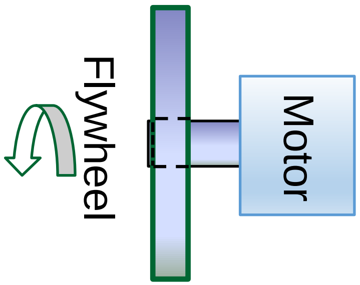


  - MSA requirement:

$$\sigma_{\mathrm{R\&R}} \leq \frac{1}{6} \text{ of the Useful Contrast.}$$

  - Sample sizes as small as two (the extremes).
  - For symmetrical distributions, the useful contrast = 6 x $\sigma_{\mathrm{R\&R}}$. Statistical power is high even with low sample size.
  - Useful contrast aids convergence to y = f (x).
- This is a strategy of choice.

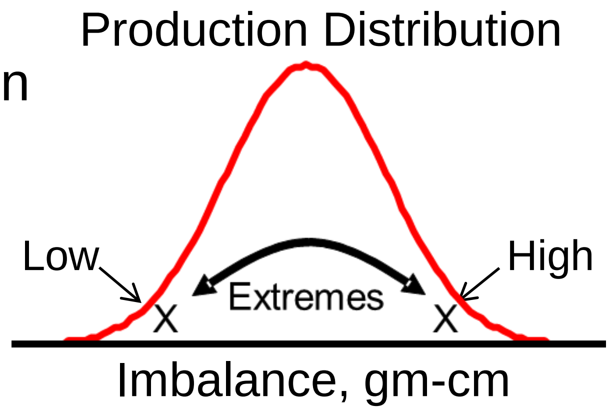
% Rejects – Vibration



Vibrates in Operation

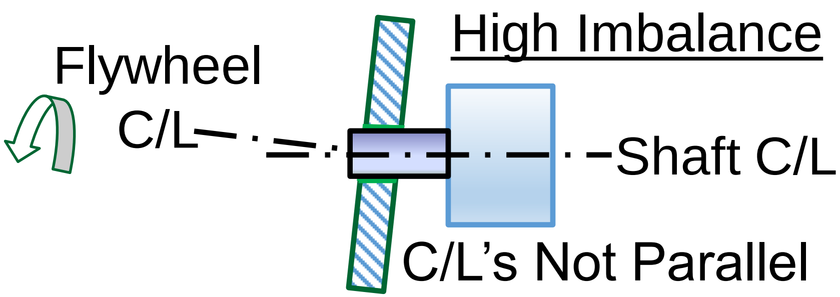
Tactical Assessment

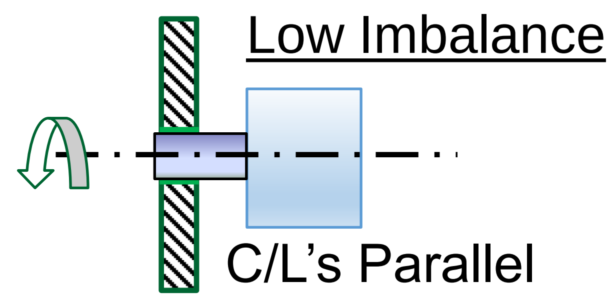
- Some assemblies vibrate even after balancing operations.
- KPOV = Imbalance, gm-cm
- Team characterized KPOV and collected extremes.



Solution Strategy: Contrast and Convergence

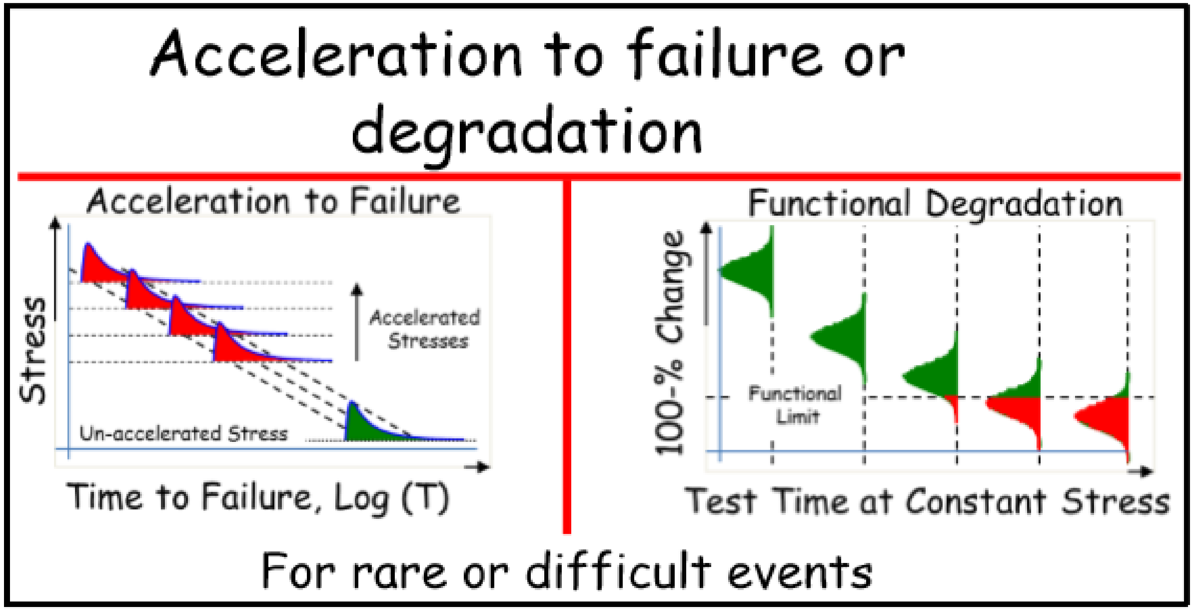
- Contrast: Analysis of extremes showed the flywheel-to-shaft centerline (C/L) out of parallel to the shaft in the high imbalance case.





- Convergence: Found (via y to x) and fixed an machining alignment issue of flywheel-to-chuck which caused the issue. Problem solved!

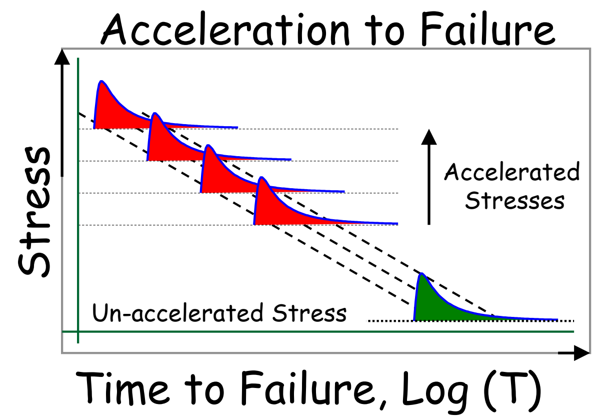
The Hierarchy – Acceleration

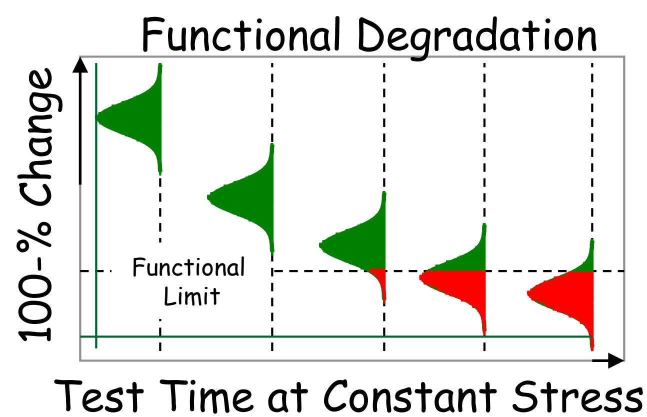


Increase stress until failure occurs quickly but the failure mode does not change.

Acceleration to Failure or Degradation

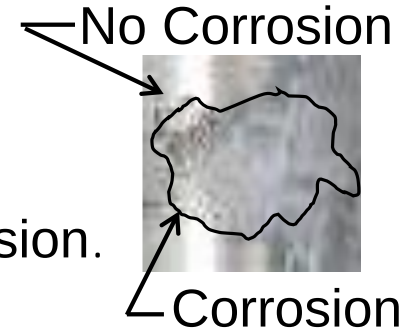
- Increase stress to force failure or measureable degradation:
  - Test at highest stress before failure mode changes. This reduces the time-to-data.
  - Accelerating stress too much may change the failure mode but even this reveals other design weaknesses.
- Often part of Contrast and Convergence.





Rework – Oil Pan Corrosion

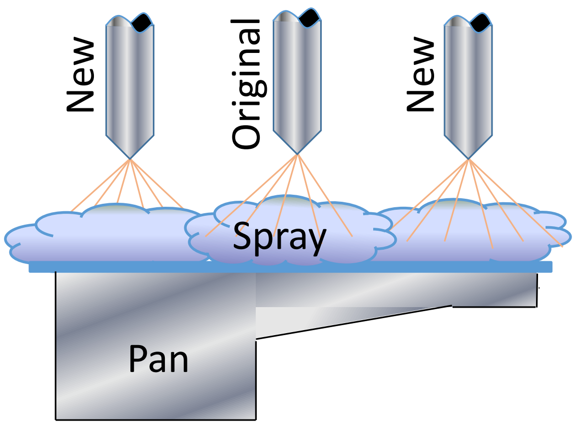
<u>Tactical Assessment</u>



- The reject rate for corrosion of aluminum oil pans was 671 DPMO within 3 weeks after manufacture.
- Problem existed for two years, KPOV = Time to Corrosion.

<u>Solution Strategy: Acceleration</u>

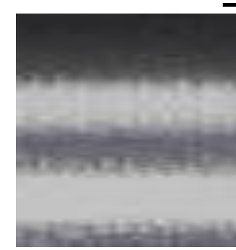
- <u>Analysis</u>: Team suspected poor preventative coverage. Current process sprays preventative onto part from a single nozzle. Designed a high temperature high humidity test to **accelerate corrosion**. Tested sprayed Vs dipped parts using the accelerated temperature and humidity.



<u>Production Sprayed</u>

Corroded in 1 day

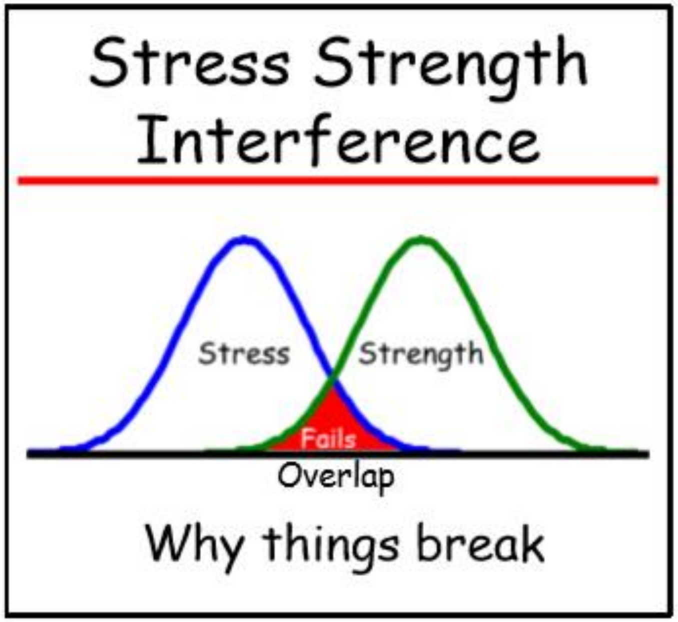
<u>Dipped</u>



Corrosion free after 30 days

- <u>Solution</u>: Team added two spray nozzles to the rig to improve coverage.
- The new process worked! Problem eliminated.

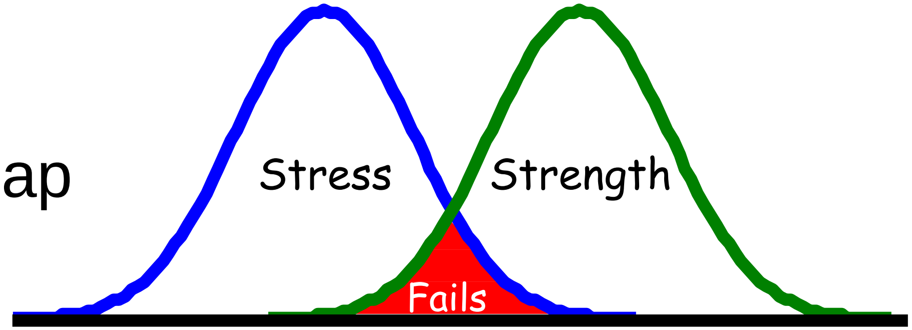
Hierarchy – Stress Strength



Study the stress and strength, based on failure analysis and physics, for clues to solution.

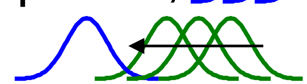
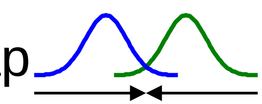
Stress Strength Interference

- Why Things Break:
  - Failure occurs in the overlap of stress and strength.



  - Design Assumption:

- If Design Assumption is Wrong – Fix the Design!

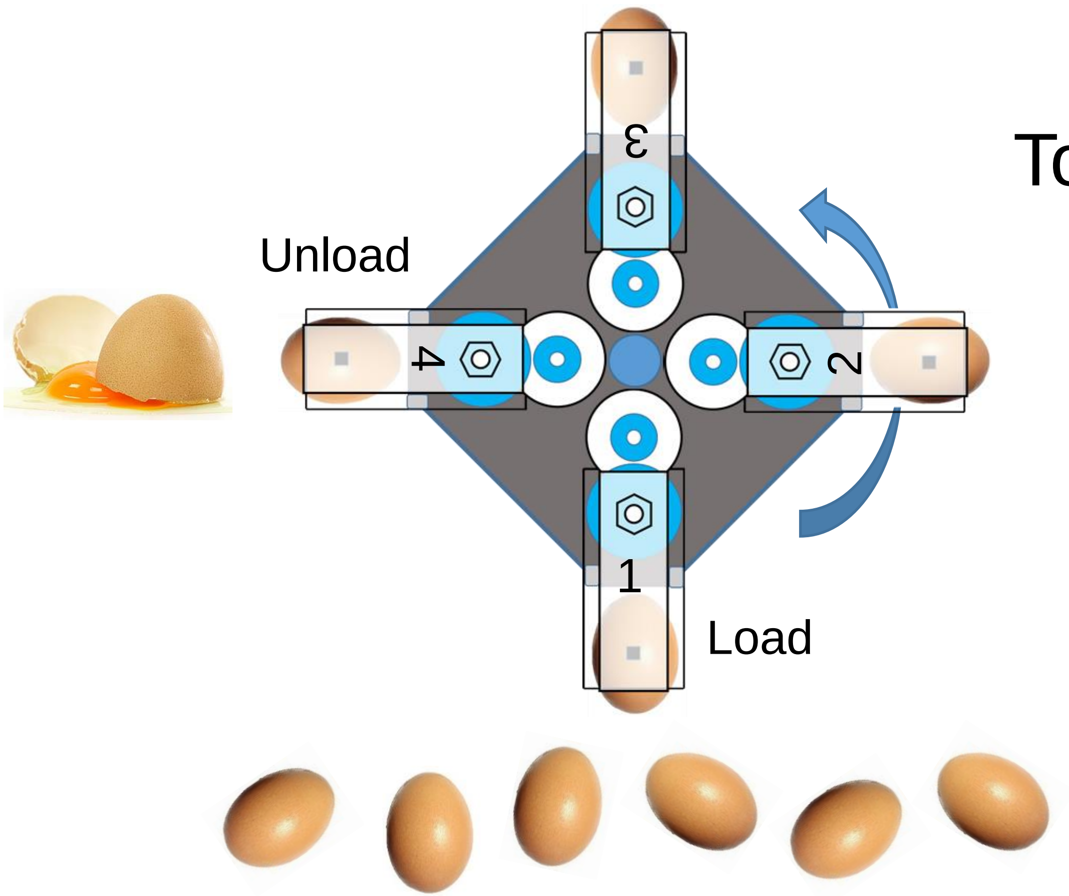
  - If Design Assumption is Correct but Failure Occurred:
    1. Stress increased until overlap happened,  or,
    2. Strength decreased until overlap,  or, there was a
    3. Stress increase AND strength decrease to overlap  .

- Often used with Acceleration.

The Case of the Cracked Eggs

Mechanically Assisted Chicken Egg Cracking Machine

Top View



% Rejects – Uncracked Eggs

Problem:

- A large restaurant uses a mechanized egg cracker to aid busy cooks when needed. The cooks report >30% failure-to-crack lately and are upset.
- The machine must crack typical chicken eggs on demand without causing the contents to splatter.

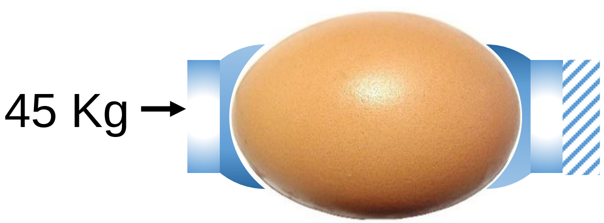
KPOV Strategy:

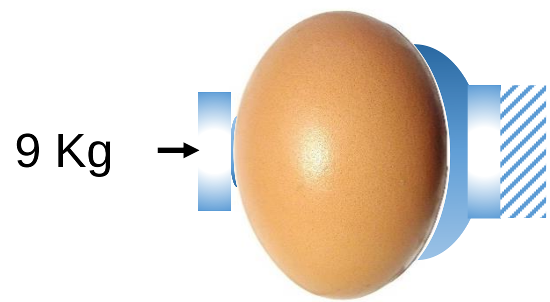
- Fracture is a physics issue. The eggs did not crack because stress did not overlap strength.
- The KPOV will be stress or strength within a key strategy of **Stress Strength Interference**.

Egg Structure and Strength

Tactical Assessment:

- Egg shells are calcium carbonate and protein structures: a biological ceramic resulting from chicken genetics and nutrition. The restaurant buys from very reputable suppliers so the egg supply is from diverse, almost random, flocks.
- Eggs are strong in compression: Higher in the long direction than in the short direction.



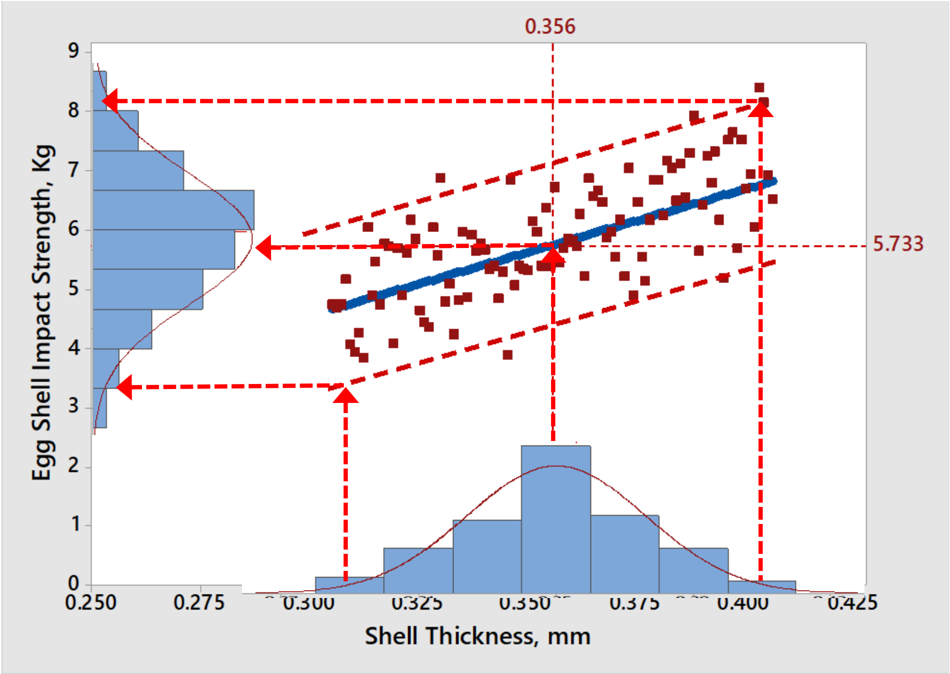


The Physics of Egg Strength

Tactical Assessment:

- Research shows that egg strength is related to shell thickness by the **Transfer Function** below:

Strength, Kg = -1.858+(21.34 x Shell Thickness, mm) $\pm$1.33 Kg



Notes:
Shell thicknesses of 1000 eggs were measured for **Transfer Function** investigation.

Mean thickness = 0.356 mm, SD = 0.0254 mm, R-sq. = 50%.

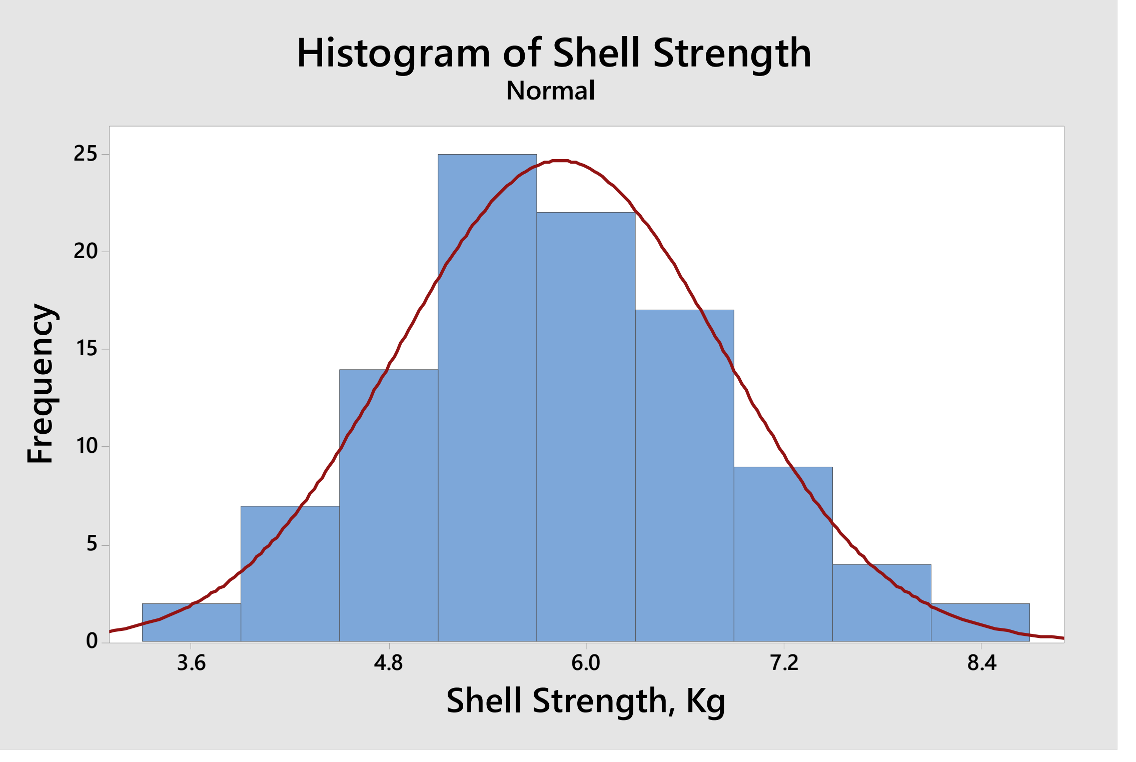
The rest of the variation is described by $\mathrm{error} = \pm 1.33\ \mathrm{Kg}$.

Load applied at 100 cm/sec (team definition of impact).

Determining the KPOV

Tactical Assessment:

- Shell strength is a symmetrical model.
- Autopsies of eggs that did not crack had nominal shell thicknesses. This Implies strength did not increase.

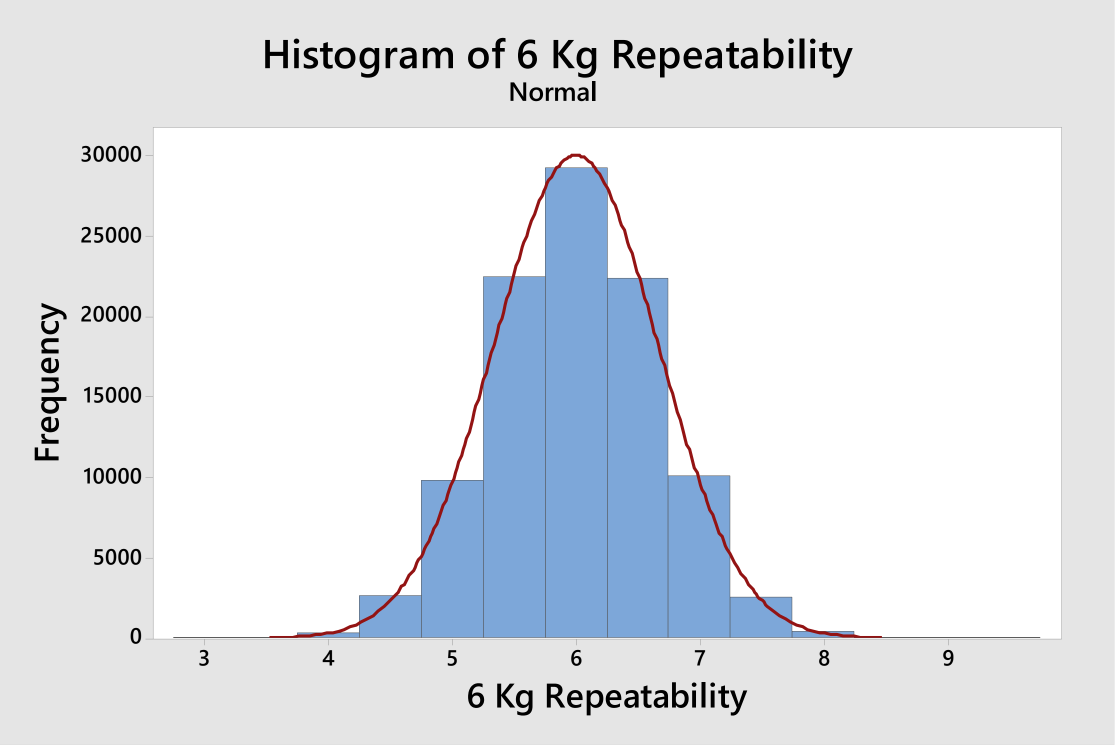


- **Stress** is the **KPOV,** measured in Kg, applied at 100 cm/minute to an egg This is also **acceleration**.

Characterizing the KPOV

Tactical Assessment:

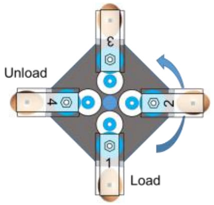
- Load variation is a symmetrical model.
- SD = 0.665 Kg
- The load is applied at 100 cm/minute. **Acceleration** is the design expectation.

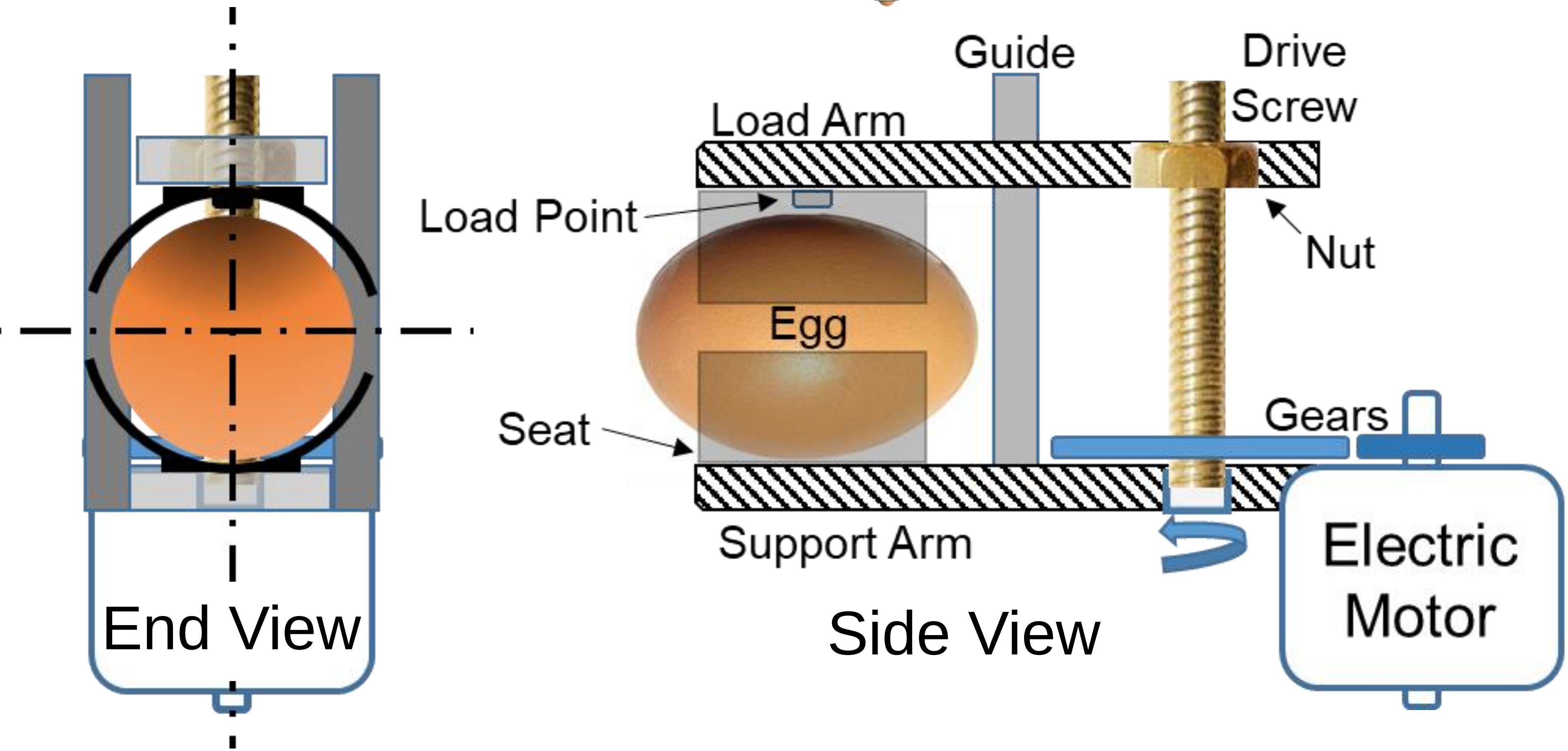


- The cracking head moves rapidly but <1 mm after preload to fulfill the designer's definition of impact.

How is the process supposed to work?

Physical Diagram:

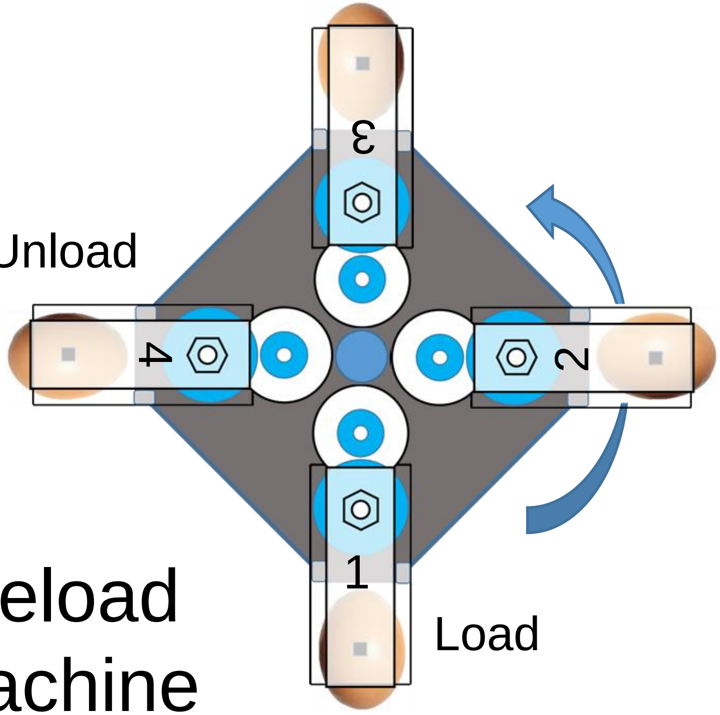




How is the process supposed to work?

Process Flow:

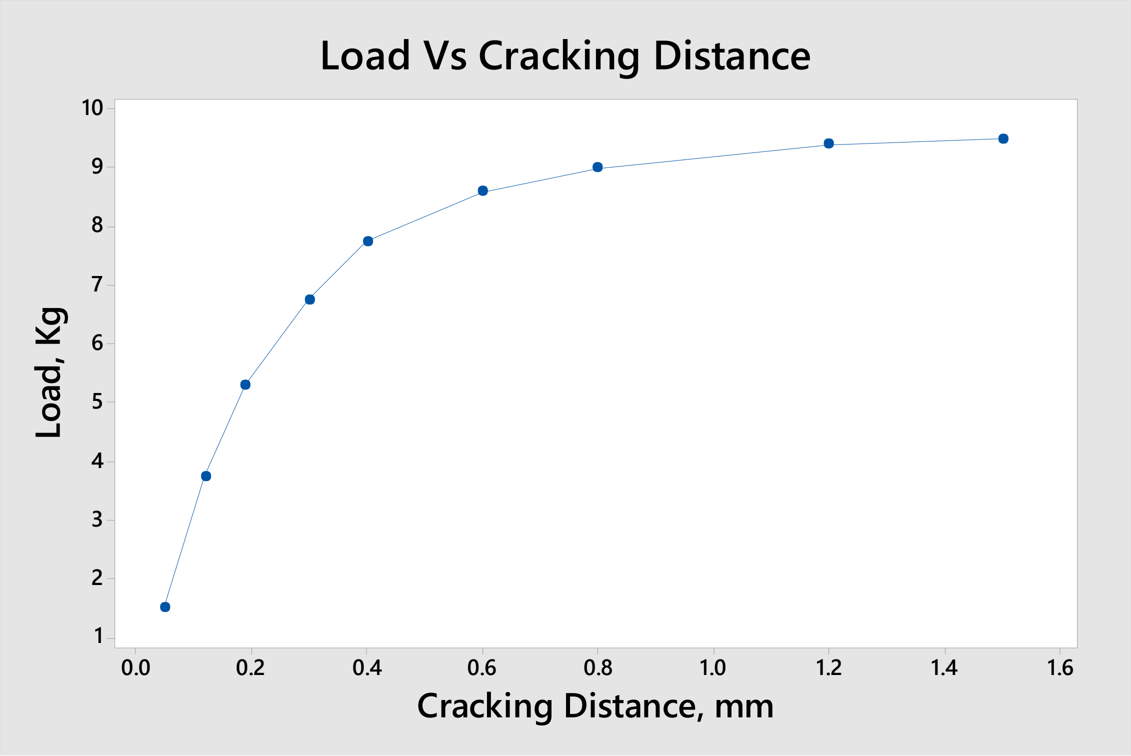
1. Load eggs only at load station.
2. Rotate unit counter-clockwise by hand.
3. When an egg reaches the unload station, the jaw will make surface contact with a preload of approximately 1 Kg. The machine then cycles about 1 mm. Egg cracks.
4. Jaw retracts 15 mm. The cook unloads the cracked egg and moves it to a frying pan.
5. Repeated as needed.



Operational Physics

"Ideal Function":

- Egg shells are brittle but do deform ~10% under load. The unit moves 1 mm in the crack cycle.
- This is the "Ideal" Load Vs Distance design plan.



- The team now has performance expectations to contrast to the restaurant's machine.

Working compared to how it should?

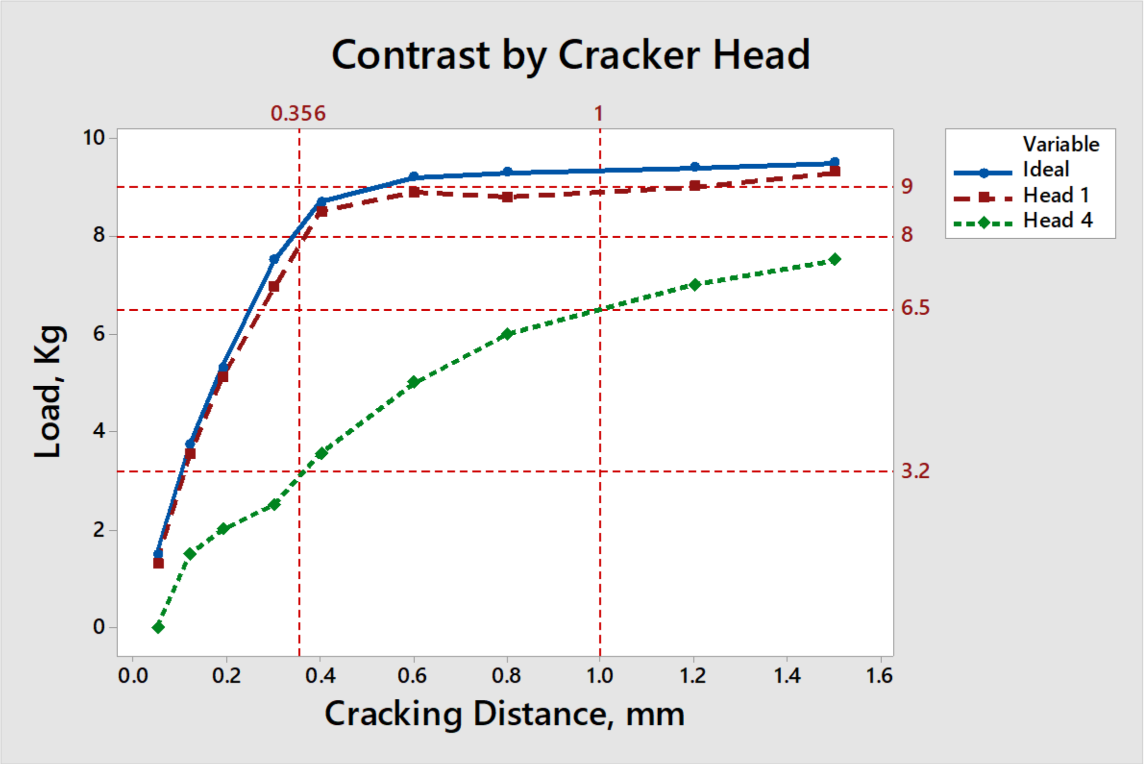
Tactical Assessment:

- The cooks observed that cracker heads 1 and 2 worked well. Head 3 failed some of the time but head 4 failed to crack the eggs frequently.
- Team chose to study head 1 Vs head 4 based on the cook's information.
- This is a **Contrast and Convergence** action.
- The first step was to performance test the two cracking heads as contrasted to the "Ideal" design performance expectations.

Contrast and Convergence

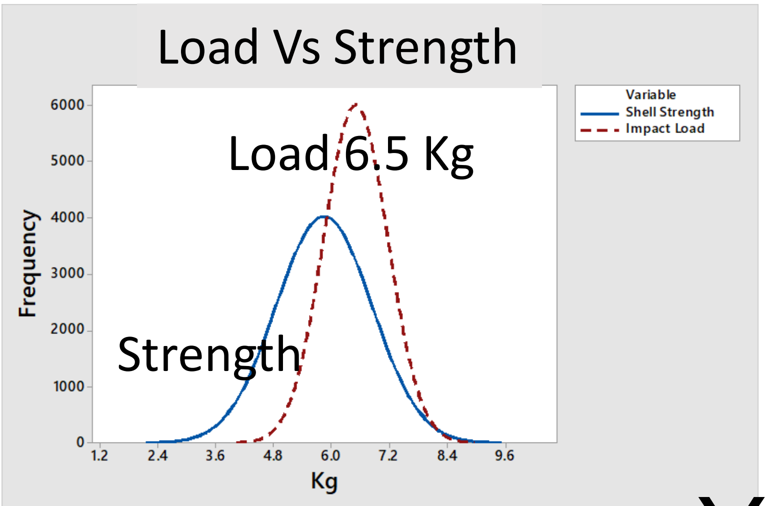
Convergence:

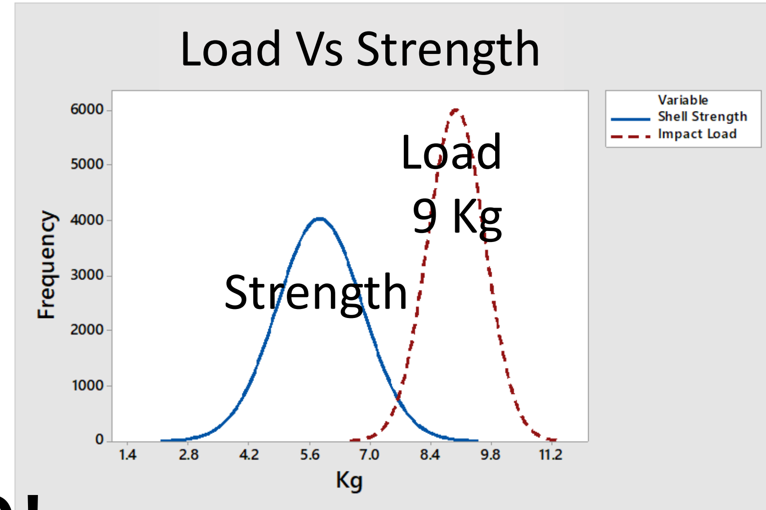
- Head 1 performed like the “ideal”.
  - 8 Kg at 0.356 mm
  - 9 Kg at 1.0 mm
- Head 4 did not run like “Ideal” or H1.
  - 3.2 Kg at 0.356 mm
  - 6.5 Kg at 1.0 mm



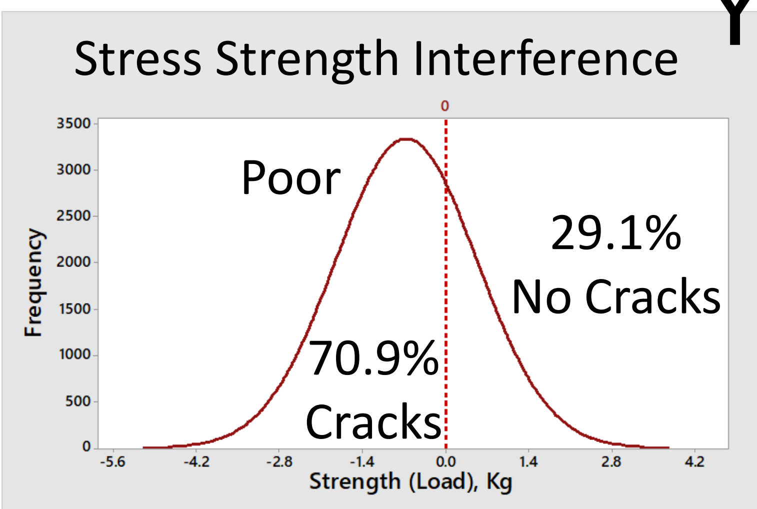
- Do performance differences explain the % failure to crack rejects plaguing the cooks?

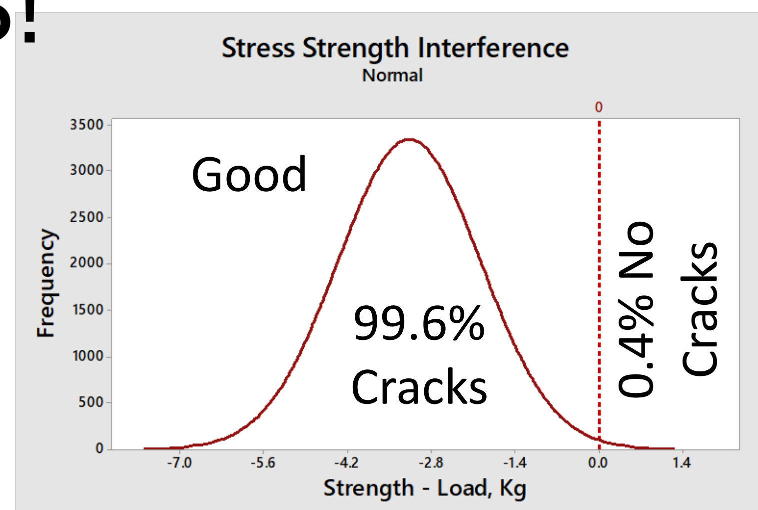
Is Difference Explained at 1 mm?





YES!



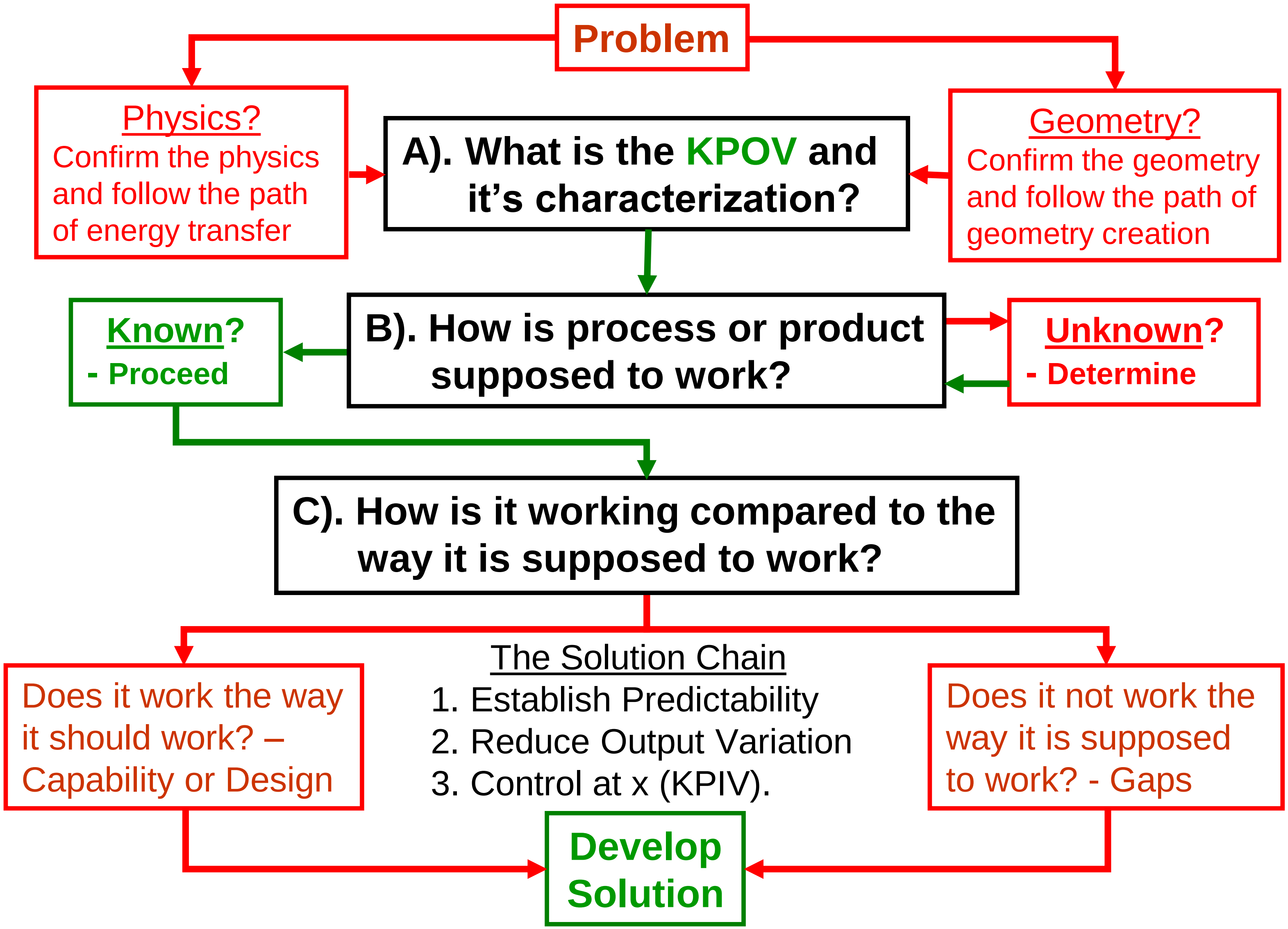


Solution

Tactical Assessment:

- The team disassembled and reassembled H1 and H4. Both performed the same as before. The problem lives in the parts not in the assembly.
- The team swapped parts between H1 and H4. Performance followed the electric motors.
- The team examined the motors and found dried egg internally gumming up motor H4.
- Replaced motors and installed a splash shield to prevent future egg contamination. Issue resolved!
- Capability is 99.6% and the restaurant is back to normal. Happy cooks, happy customers!

Follow the Path!



Summary

- Strategy first, then tactics, then tools!
- Use the Strategic Problem Solving Model:
  1. Determine and Characterize the KPOV.
  2. Find out how the process is supposed to work.
  3. Compare how it is working to how it should work.
- Apply the 5 key solution strategies.
- A parting KISS:
  - "**K**eep **I**t **S**tatistically **S**imple", and,
  - "**K**eep **I**t **S**trategically **S**ound"
- The solution chain is waiting, get to work!

Thank you!

For questions, comment or discussion, contact:

Bruce A. Barth
6-Sigma Master Black Belt
Email: theprocessfactor@gmail.com
Cell Phone: 419-704-3666