

ASQ Baltimore Section Dinner Meeting

December 09, 2010

Beyond Gauge R&R: An improved measurement system capability statistic

Presented by:

**J. Eric Whichard
JE Whichard & Associates
Columbia, Maryland
Eric.Whichard @ verizon.net**

As recently presented at the



2010 Fall Technical Conference
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Eric.Whichard@Verizon.net

54th Annual Fall Technical Conference

2010 – Birmingham, AL (Friday, October 8th, Track B - Special Applications, 1:30pm)

Beyond Gauge R&R: An improved measurement system capability statistic

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My perspective as a practitioner...

- Recently retired from the **CPI** (Chemical & Process Industry)
- 25+ years, using statistics in the **CPI**
- in 1990, Six Sigma / Gage R&R introduced
- became a **Black Belt**... then **Senior Black Belt**
- gravitated to / eventually specialized in **MEASUREMENT systems**
 - especially as related to measured **process capability**
 - lead numerous projects, observed many, many more
 - taught many classes (general Six Sigma, Measurement Systems, etc.)
- noted some **confusion**
 - **interpretation, implications of R&R** esp. regarding Cp, Cpk, Pp, Ppk
- wondered **WHAT MIGHT HELP**
 - process owners to better understand and use R&R and its implications, to improve their processes
 - **BBs and other Stat-Heads to better explain / facilitate that understanding / use**

Agenda

- Short review: what is Gauge R&R
- Interpretation (and an associated “eccentricity”)
- Understanding this eccentricity
- Addressing the eccentricity
 - a proposed new statistic to be used with R&R
- Understanding, using, interpreting the new stat
- Proposal
- Discussion / Reaction to the proposal

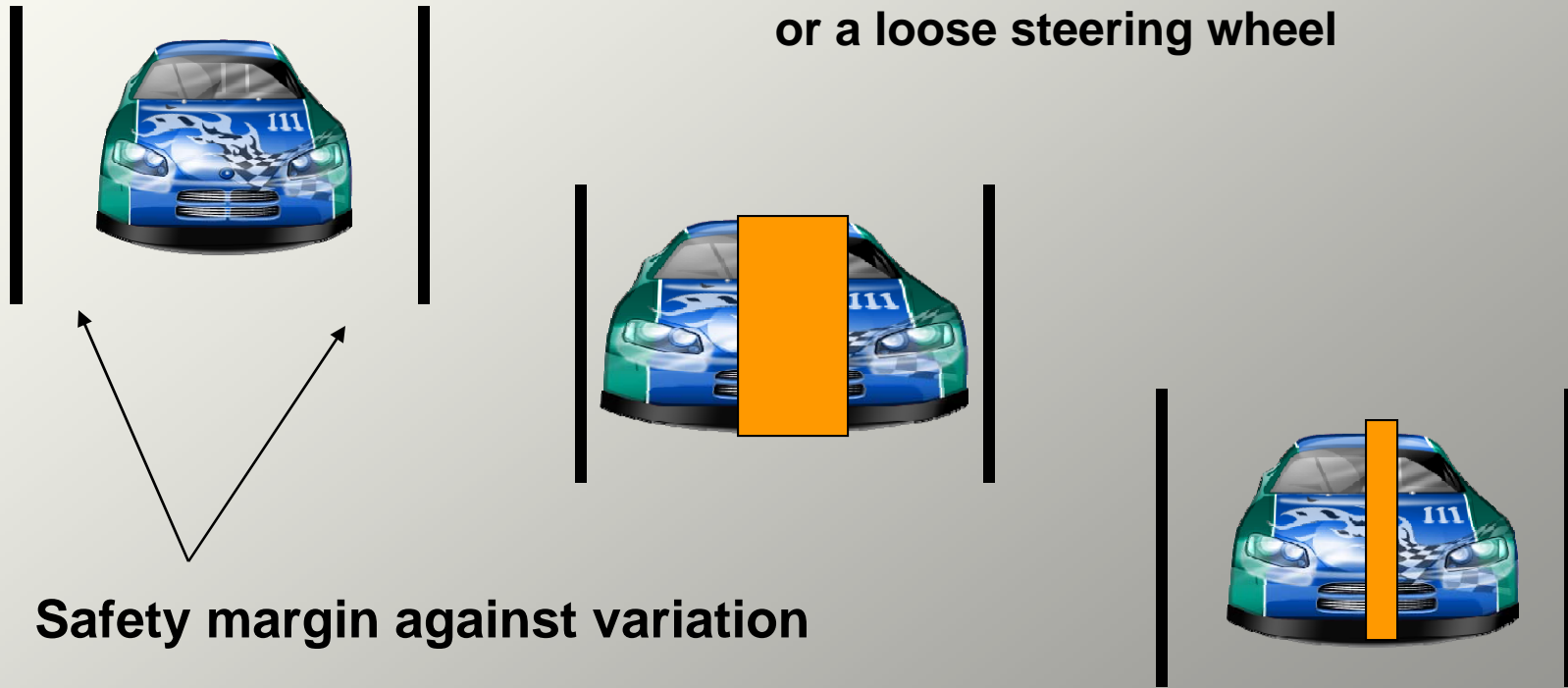
What is Gauge R&R?

- One of several metrics of **measurement system (MS) capability** (or lack thereof)
 - R&R... P/T... # of discrete categories... **S/N**... etc.
 - » others can be more useful, depending on circumstances
 - » focus here on R&R
- R&R compares MS related **variation**...
 - expressed as a standard deviation, σ_{MS}
- ...with **Total observed variation**
 - also expressed as a standard deviation, σ_T
 - » where σ_T includes both σ_{MS} and σ_P
 - » σ_P being variation related to the measured process, as distinct from variation added to the total by the MS



Why does variation matter?

Like a dirty windshield,
or a loose steering wheel



Safety margin against variation

What is Gauge R&R?

- as a **RATIO** $R\&R = \sigma_{MS} / \sigma_T$ of σ_{MS} to σ_T



- a ratio of Standard Deviations
- often expressed as a percentage (%R&R)
- σ_{MS} and σ_T typically estimated by a gauge study
 - » details of which are not covered here
- called R&R since it comprises two components of measurement variation: Repeatability and Reproducibility



Why is R&R?

σ_{MS} - the “Voice of the Measurement System”
 σ_P - the “Voice of the Process”

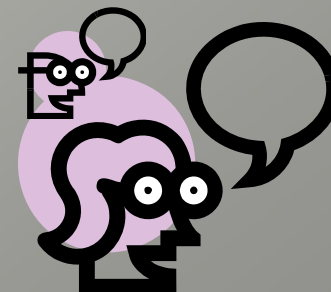
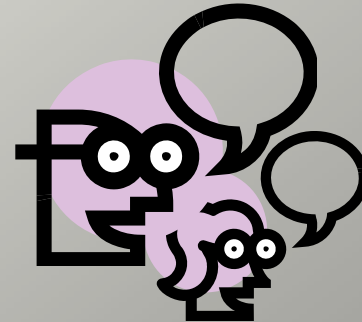
When we measure...

- What we **WANT** to hear is the pure Voice of the Process – the process that is being measured 
- What we **GET** is the Voice of the Process, but with the Voice of the MS mixed in 
- σ_P is “confounded with” σ_{MS} inflating σ_T which
 - hinders our ability to control / improve the process, and thereby
 - reduces the **CAPABILITY** of the process (Cp, Cpk, etc.)

To what extent... how much?

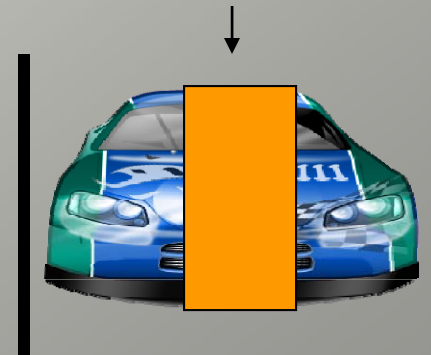
How is Gauge R&R used?

- **How much impact is σ_{MS} having on σ_T ?**
 - how much NOISE is the voice of the MS adding to the SIGNAL of the voice of the process?
- Is this impact acceptable?
- If not, can we reduce that impact?
- **Improving MS is often less expensive, more immediately do-able, than changing process**



How is Gauge R&R used?

- How much?
 - Gauge R&R is generally interpreted as...
 - ... that portion of Total variation attributable to the Measurement System, or
 - ... that portion of observed variation “used up” or “consumed by” the MS
 - OTHERS???

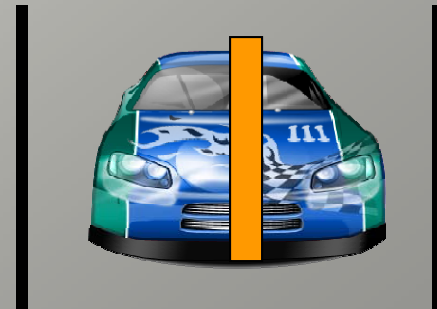


Key points so far

- R&R is a RATIO...
of standard deviations

$$R\&R = \sigma_{MS} / \sigma_T$$

- R&R is generally interpreted as the portion of Total observed variation σ_T attributable to Measurement System variation σ_{MS}



...portion attributable to...

Let's focus now on the second point

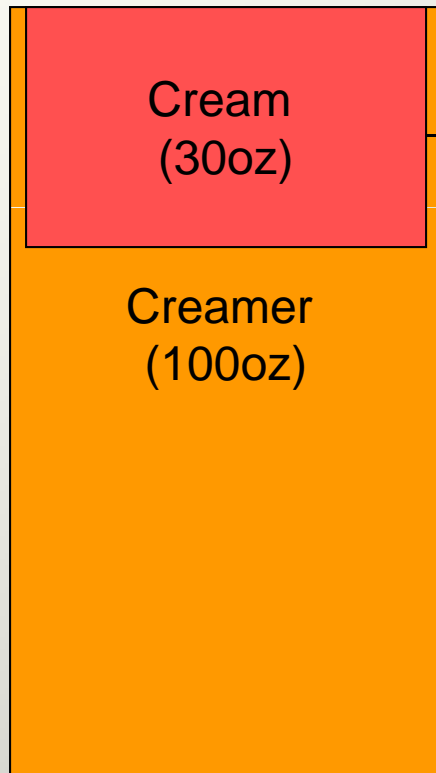
- R&R is “the portion of σ_T attributable to σ_{MS} ”

which will lead us back to the first point

...portion attributable to...

- A “thought experiment”
- Three scenarios...

...portion attributable to...



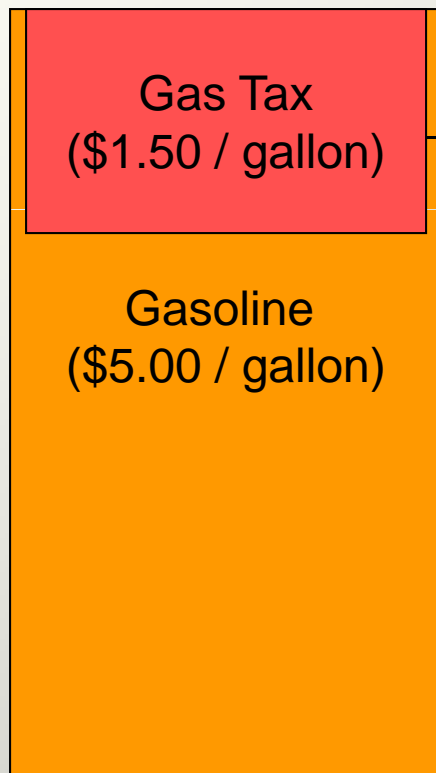
- 100%
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 00

- A coffee creamer is packaged in 100oz containers
- 70oz of milk is added to the package, followed by 30oz of cream
- To make a more healthful product, the manufacturer reduces the amount of cream to $\frac{1}{2}$ of the former amount.
- How large, in oz, should the new package be?



$$100 - \frac{1}{2} (30) = 85$$

...portion attributable to...



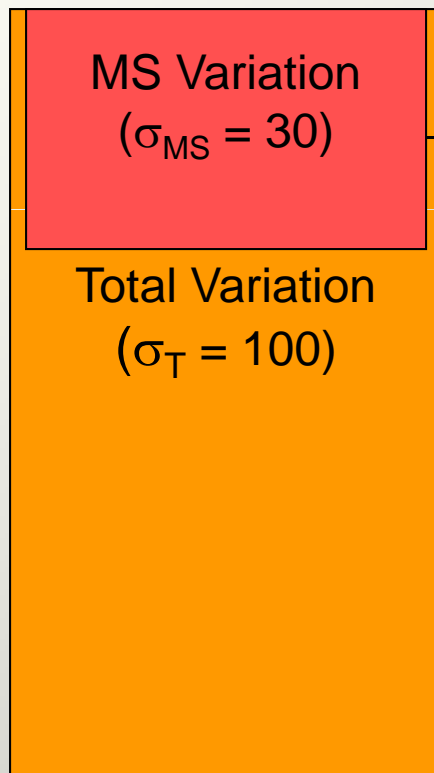
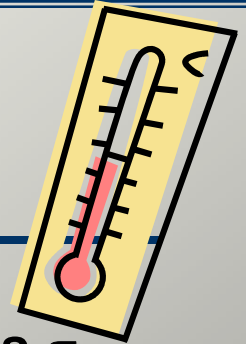
- 100%
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 00

- Gasoline sells for \$5.00/gal
- Gas tax is \$1.50, or 30% of the price
- The new administration cuts the per gallon tax by half
- How much do you expect to pay per gallon now? By how much is your price reduced?

$$5.00 - \frac{1}{2} (1.50) = 4.25$$
$$\frac{1}{2} (1.50) = 0.75, 15\%$$



...portion attributable to...



- 100%
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 00

- A gauge study estimates σ_T as 100, and σ_{MS} as 30, for an R&R of 0.30 (or 30%)
- An MS improvement team reduces σ_{MS} to $\frac{1}{2}$ of its former amount
- How large do you expect σ_T to be now? By how much do you expect to see it reduced?

$100 - \frac{1}{2} (30) = 85$
 $\frac{1}{2} (30) = 15, 15\%$
REALLY ???????

...portion attributable to...

- Let's look more closely!!
- We can add and subtract ounces, dollars

- 100oz of old creamer - $\frac{1}{2}$ (30oz of cream)
= 85oz of new creamer
- a **15% reduction** in total volume / package size
- due to a 50% reduction in cream

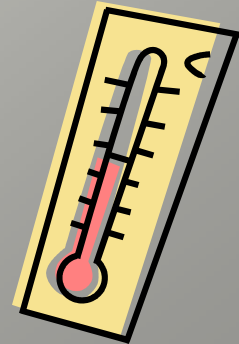
- \$5.00 / gallon of gas - $\frac{1}{2}$ (1.50 former tax / gallon)
= \$4.25 / gallon new price
- a **15% reduction** in total price per gallon
- due to a 50% reduction in tax



...portion attributable to...

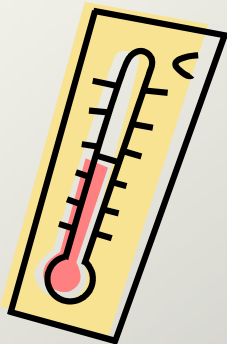
- **BUT, can we add and subtract standard deviations?**
 - 100 old σ_T - $\frac{1}{2}$ (30 old σ_{MS})
= 85 new σ_T
 - a **15% reduction** in Total variation (σ_T)
 - due to a **50% reduction** in MS variation (σ_{MS})... and R&R

?



...portion attributable to...

- BUT, can we add and subtract standard deviations?
- **NO!!!** --- but a lot of people don't realize that!
 - » and that sets them up for misunderstanding and disappointment regarding the impact of the MS on observed variation
 - » ...regarding expected total variation reduction due to Measurement System improvement (σ_{MS} reduction)
 - » **this is “the eccentricity”** - how R&R can mislead
 - » Mised... Disappointed... Embarrassed...
 - » Wasted time... effort... money
 - » Eroded credibility

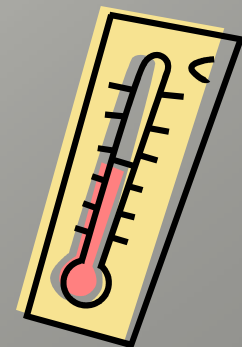


The Eccentricity

- We must add / subtract variances (σ^2), then take sqrt
 - $\sigma_T^2 = \sigma_P^2 + \sigma_{MS}^2$ and $\sigma_P^2 = \sigma_T^2 - \sigma_{MS}^2$

The Eccentricity

- We must add / subtract variances (σ^2), then take sqrt
 - $\sigma_T^2 = \sigma_P^2 + \sigma_{MS}^2$ and $\sigma_P^2 = \sigma_T^2 - \sigma_{MS}^2$
 - we had $\sigma_T = 100$ and $\sigma_{MS} = 30$ for an R&R of 0.30 or 30%
 - $\sigma_P^2 = 100^2 - 30^2 = 10,000 - 900$
 - $\sigma_P^2 = 9,100$ ($\sigma_P = 95.4$)
 - we reduced σ_{MS} to $\frac{1}{2}$ of former level, so now...
 - $\sigma_T^2 = 9,100 + (0.5 * \sigma_{MS})^2$
 $= 9,100 + [15^2=225] = 9,325$
 - $\sigma_T = 96.6$ (96.566)
 - a 3.4% reduction in Total variation – NOT 15%
 - due to a 50% reduction in MS variation (σ_{MS})



The Eccentricity

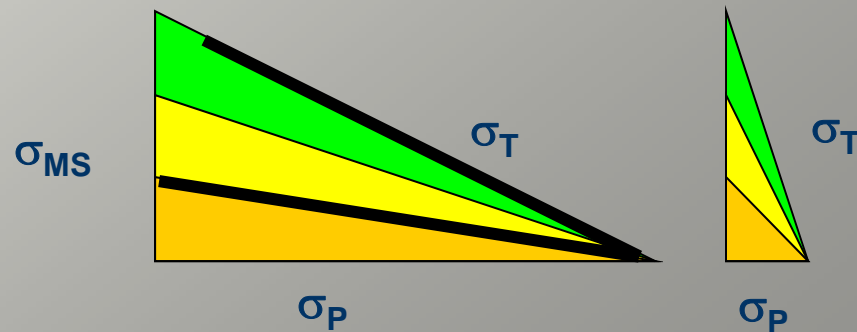
- Has been illustrated by others using the Pythagorean Theorem



- the hypotenuse = the sqrt of the sum of the squared sides
- $c^2 = a^2 + b^2$ $c = \text{sqrt}(a^2 + b^2)$
- note how little the length of the hypotenuse σ_T is affected by relatively large variations in the upright σ_{MS} side of the right triangle as long as the σ_{MS} side is significantly smaller than the base σ_P side

- $\sigma_P = 6$ $\sigma_{MS} = 3, 2, 1$ $\sigma_T = 6.71, 6.32, 6.08$ R&R = 45, 32, 16%

$$\sigma_T^2 = \sigma_P^2 + \sigma_{MS}^2$$



Addressing the “eccentricity”

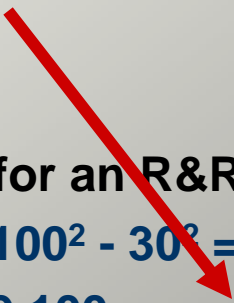
- Avoid misunderstanding, disappointment, etc.
 - How do we help do that?
-

* client (external / internal), project champion

Addressing the “eccentricity”

- Avoid misunderstanding, disappointment, etc.
 - How do we help do that?
-
- **R&R takes a Measurement System perspective**
 - its focus is on σ_{MS} (as compared to σ_T)
 - **What if we look at things from a Process perspective**
 - and focus is on σ_P (as compared to σ_T) ??
 - **After all, that’s often our CUSTOMER’s* perspective**
 - * client (external / internal), project champion

Addressing the “eccentricity”

- Revisiting an earlier slide
 - note that σ_P the sqrt of σ_P^2 is **95.4** (95.394)
 - we had $\sigma_T = 100$ and $\sigma_{MS} = 30$ for an R&R of 0.30 or 30%
 - $\sigma_P^2 = 100^2 - 30^2 = 10,000 - 900$
 - $\sigma_P^2 = 9,100$ ($\sigma_P = 95.4$)
- 

Addressing the “eccentricity”

- Knowing that σ_P is 95.4 tells us RIGHT AWAY that
 - no matter how small we can make σ_{MS}
 - ... even if we can make σ_{MS} effectively ZERO
 - σ_T can NEVER be smaller than 95.4
 - σ_P is 95.4, and σ_T is 100... so $\sigma_P / \sigma_T = 0.954$ or **95.4%**
 - Mr. Process Owner: that's AS GOOD AS IT GETS in terms of improving Total variation by improving the MS

Addressing the “eccentricity”

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 - σ_P is 95.4, and σ_T is 100... so $\sigma_P / \sigma_T = 0.954$ or 95.4%
 - Mr. Process Owner: that’s as GOOD AS IT GETS in terms of improving Total variation by improving the MS
 - σ_P / σ_T might it be a good metric
from the Process Owner’s perspective?
 - more meaningful, less confusing?

A new metric: PVI

- σ_P / σ_T -- a ratio (or index) like R&R but re: the Process
 - » can't call it P/T... that's already taken
- For now, lets call it **PVI -- Process Variation Index**
- PVI is that portion of Total observed variation σ_T attributable to Process variation σ_P – the Voice of the Process
- ... larger is better, in contrast with R&R
- PVI is that portion of σ_T that will remain even if the MS is improved to the point that σ_{MS} is effectively zero
- and a “corollary” metric **1-PVI (one minus PVI)...**

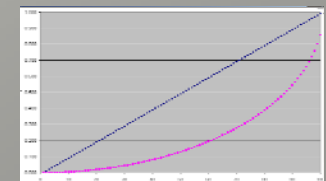
Corollary Metric: 1-PVI

- 1-PVI (one minus PVI) is that portion of Total observed variation σ_T remaining after Process variation σ_p is accounted for – that portion **attributable to the MS** σ_{MS} – the true Voice of the Measurement System
- ... that portion that can potentially be reduced through improvement of the MS (reduced σ_{MS})
- ... **how we generally think of R&R**

- So where does that leave R&R?

Where does that leave R&R?

- 1-PVI is that portion of total observed variation σ_T remaining after process variation σ_p is accounted for – that portion attributable to the measurement system σ_{MS}
- ... that portion that can potentially be reduced through improvement of the MS (reduced σ_{MS})
- ... how we generally think of R&R
- **So what is R&R?** The magnitude of σ_{MS} compared to σ_T
A useful ratio of σ_{MS} to σ_T
An INDEX of MS adequacy
(but non-quantitative)



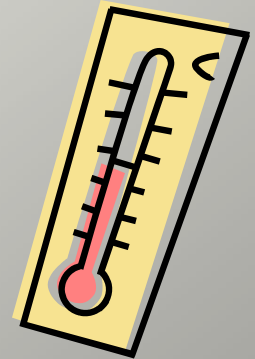
A linear representation of a NON-linear reality

PVI and 1-PVI

- PVI and 1-PVI may be metrics that are more clear, and therefore more useful especially to the Process Owner
- ...since they look at the components of σ_T from a PROCESS perspective (σ_P / σ_T), rather than a Measurement System perspective (σ_{MS} / σ_T)
- ... to be used ALONG SIDE of / with R&R
- we've seen how PVI relates to R&R (process vs. MS centric - σ_P rather than σ_{MS} / σ_T)
- we should understand how 1-PVI relates to / differs from traditional R&R

Understanding 1-PVI (and PVI)

- Returning again to our simple example
 - $\sigma_T = 100$, $\sigma_{MS} = 30$, R&R = 0.30 or 30%
 - $\sigma_P = 0.954$, PVI = 0.954, 1-PVI = 0.046 or 4.6%
- **NOTE!** R&R of 30%... but... 1-PVI of only 4.6% !!!???
- Remember R&R's inherent "eccentricity"
- ... which 1-PVI eliminates
- **4.6% is the REAL WORLD.** 30% is just an index
- If R&R is 10%, then PVI = 99.5 (99.499) and 1-PVI is only 0.5%

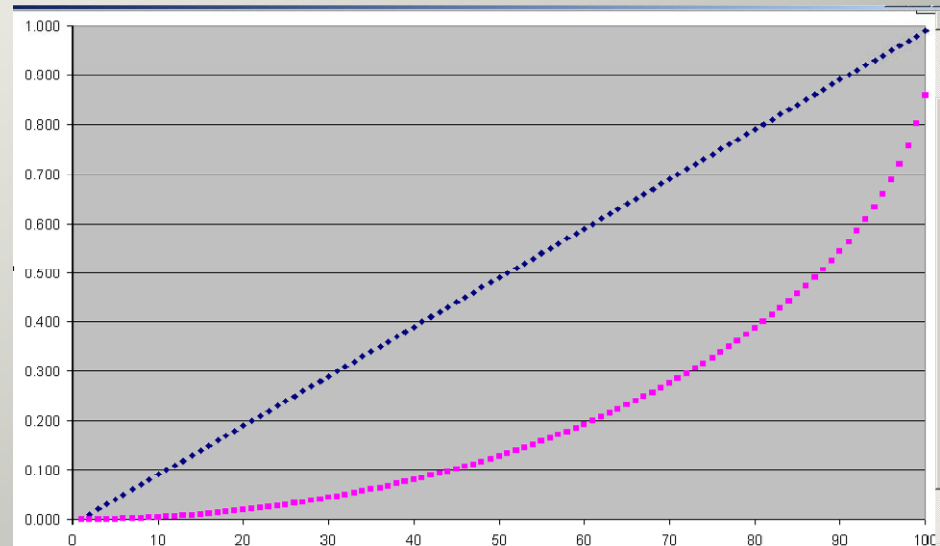


Understanding 1-PVI

- **Could it be that those popular, but somewhat mysterious R&R guidelines**
 - > 30% R&R is unacceptable
 - < 10% R&R is excellent
- **... have really been saying all along that**
 - > 4.6% (> approx. 5%) 1-PVI is unacceptable
 - < 0.5% 1-PVI is excellent
- **????????????????**

Understanding 1-PVI

- R&R and 1-PVI
 - as σ_{MS} rises from 1-100
 - with σ_T always 100
 - R&R rises linearly
 - 1-PVI rises more slowly and non-linearly as expected



– %R&R corresponds to %1-PVI

- 10% 0.5%
- 30 4.6
- 40 8.4
- 44 just over 10%

- 60% 20%
- 80 40
- 90 56
- 96 72



Interpreting and Using 1- PVI

- If 1-PVI is small (eg. <5%) then significant reduction in σ_T **cannot** be expected by improving the Measurement System. Process variation must be improved.
 - » After which Measurement System may need improvement, too.

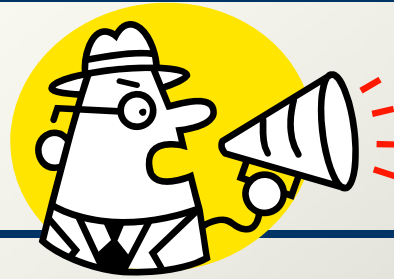
Interpreting and Using 1- PVI

- **Choose limits on 1-PVI reflecting tolerance for inflation / noise – and real world limitations.**
 - R&R 30%... 1-PVI 4.6 (approx. 5%) upper limit?
 - R&R 43-44%... 1-PVI 10% upper limit?
 - sounds crazy but
 - R&R 60%... 1-PVI 20% ?
- sometimes, especially in the CPI,
we're very lucky to achieve <1-PVI of 10%

Interpreting and Using PVI

- If PVI is **LARGE** (eg. >95%) then the amount of total variation σ_T attributable to the measurement system σ_{MS} is relatively small. Addressing MS variation will have minimal impact on total variation. To improve total variation, process variation σ_P must be addressed.
- Choose limits...

Proposal



- During MEASUREMENT SYSTEMS ANALYSIS (MSA)
- Especially gauge studies where R&R is calculated
 - In addition to σ_{MS} and σ_T also calculate σ_P
 - In addition to σ_{MS} / σ_T (R&R) also calculate σ_P / σ_T (PVI)
 - ----- and 1-PVI
- Use PVI to assess the Process against Total variation
 - if useful, adopt appropriate lower warning / limits on PVI
- Use 1-PVI to assess the MS against Total variation
 - similar to how we use R&R – along with R&R
 - adopt appropriate upper warning / limits on 1-PVI
 - » as we do now with R&R

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Beyond Gauge R&R: An improved measurement system capability statistic (1- PVI)

THANK YOU FOR YOUR ATTENTION. **DISCUSSION??**

J. Eric Whichard
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Columbia, Maryland
Eric.Whichard @ verizon.net

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Intro – J. Eric Whichard

- of Columbia, Maryland...
 - » just a few miles from Washington DC, Northern Virginia, and Baltimore
- recently retired after 25+ years in the CPI...
- ...specialty chemicals mfg (catalysts & other engineered materials)
- as a Quality Manager (N/S America), and Senior SSBB
- with special interest in MEASUREMENT SYSTEMS / MSA
- BS Chemistry, MBA
- ASQ - CQE, CSSBB, CMQ/OE (I still call it CQM)
- adjunct faculty (part time)
- certification prep course instructor

- here to explore with you possible new measurement system capability metrics that are similar to, but different from in significant ways, our old friend Gauge R&R

Gage R&R for ASAP 2400 Zeolite Surface Area

Source	VarComp	%Contribution (of VarComp)		
Total Gage R&R	24.8	1.72		
Repeatability	0.8	0.06		
Reproducibility	24.0	1.66		
Tech	1.4	0.10		
Tech*Material	22.6	1.57		
Part-To-Part	1417.7	98.28		
Total Variation	1442.5	100.00		

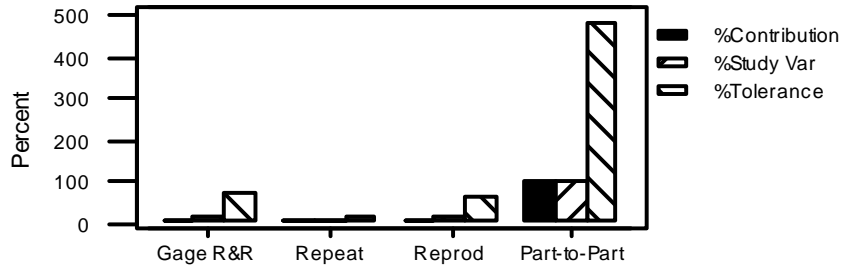
Source	StdDev (SD)	Study Var (5.15*SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	4.9800	25.647	13.11	64.12
Repeatability	0.8944	4.606	2.35	11.52
Reproducibility	4.8990	25.230	12.90	63.07
Tech	1.1850	6.103	3.12	15.26
Tech*Material	4.7535	24.481	12.52	61.20
Part-To-Part	37.6527	193.912	99.14	484.78
Total Variation	37.9806	195.600	100.00	489.00

Number of Distinct Categories = 11

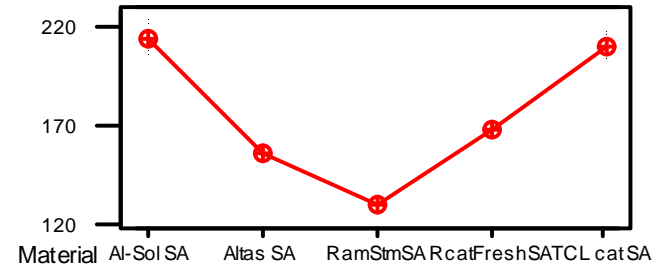
SA

Gage name: SA - 3 catx 3 ope x 3 rep = 27
 Date of study:
 Reported by: ser
 Tolerance: 40
 Misc:

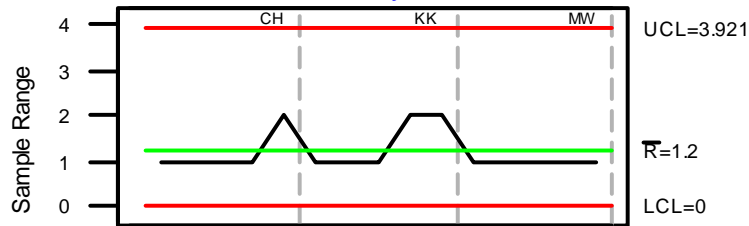
Components of Variation



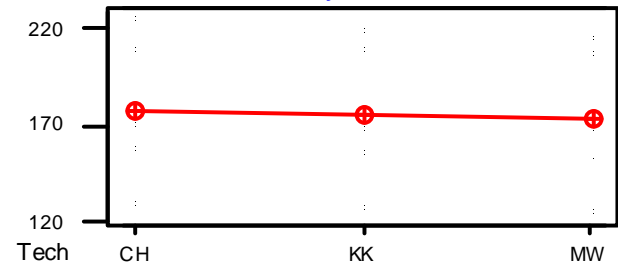
By Material



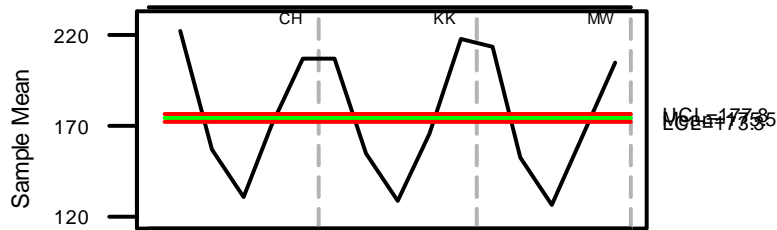
R Chart by Tech



By Tech



Xbar Chart by Tech



Tech*Material Interaction

