Separate part variation from measurement variation

Distinguish measurement-study design from supplied variance estimates and explain why standard-deviation and variance percentages differ.

Twenty percent and four percent can both be correct

Fictional case: a gauge study uses ten representative parts, three operators and two repeated measurements, giving 60 readings. The core exhibit supplies repeatability SD .003 mm, reproducibility SD .004 mm and total study SD .025 mm. Metrologist Eve must explain a report that labels gauge variation both 20% and 4%, without claiming these components were calculated from an unseen raw dataset.

Your role and the reference condition

Measurement-system specialist and inspection owner
Normal: The study represents intended parts, appraisers and conditions; repeats preserve identity and avoid memory effects; the analysis method and denominator are explicit.
Gap: A manager adds .003 and .004 to obtain .007 mm and treats the larger percentage as evidence that the smaller one is dishonest.

Work within these conditions

1. Components are supplied estimates for an arithmetic illustration.

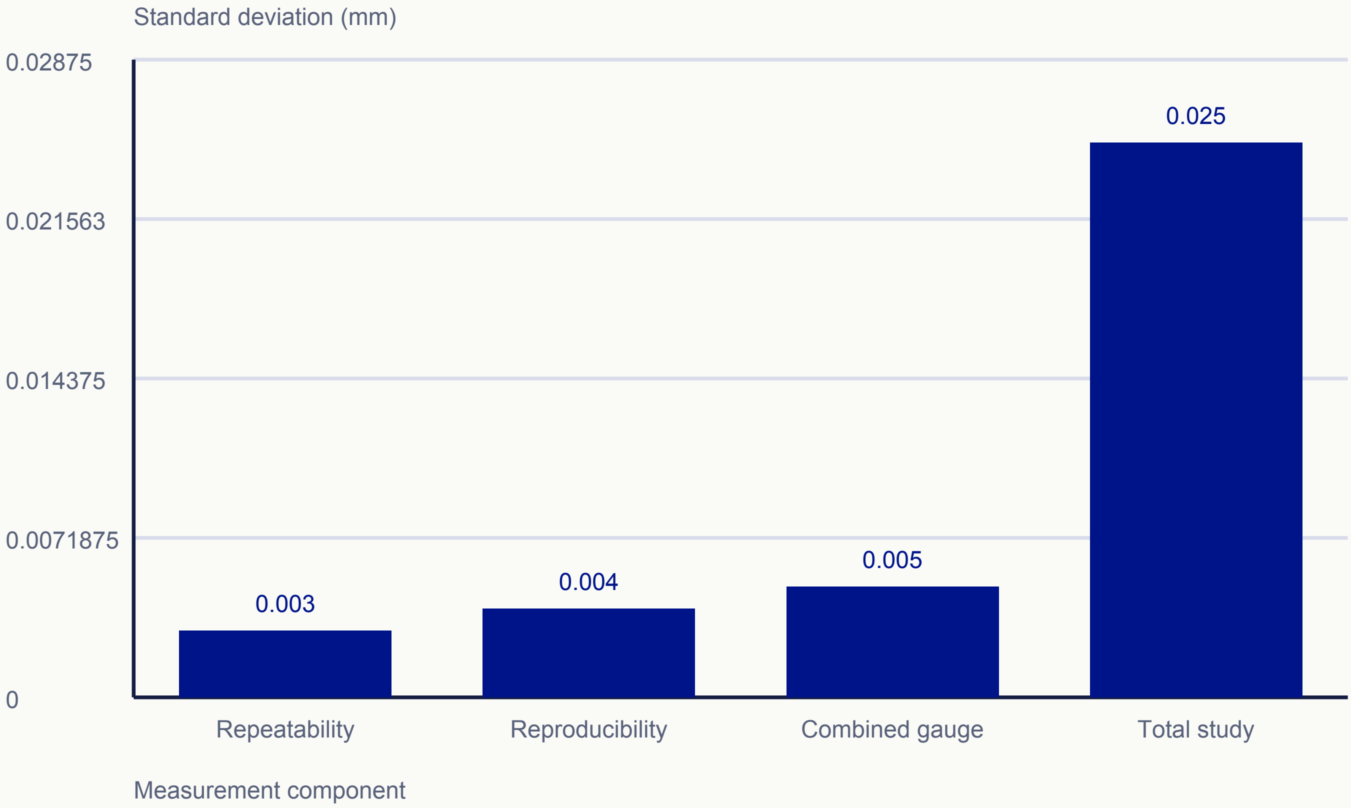
2. No universal acceptance threshold or complete MSA conclusion is supplied.

Fictional teaching case. Supplied observations support the exercise; proposed actions are not verified customer results.

See how the method works

A measurement study separates variation due to the measurement system from variation between parts. Select parts and conditions that represent the intended use, and use a design appropriate to whether repeated measurements are possible. Randomized, blinded repeats reduce memory and order effects. Repeatability and reproducibility are distinct components; estimated independent variances combine before taking a square root. Consequently, a percentage based on standard deviations is not the same as a percentage of variance. Do not treat a sample design or a generic percentage as a universal acceptance criterion. Interpret the result against the measurement decision, risk, resolution and other relevant sources of measurement error.

Supplied standard deviations (mm)



20%
Study variation ratio / % of total SD

4%
Variance contribution / % of total variance

$\text{sqrt}(0.003^2 + 0.004^2) = 0.005$ mm

$100 \times 0.005 / 0.025 = 20\%$

$100 \times 0.005^2 / 0.025^2 = 4\%$

Independent estimated variance components are supplied. Combine variances, not SDs; two percentages have different denominators. No acceptance threshold implied.

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Follow the evidence and decisions

Inspect the supplied case inputs

Study item	Supplied value
Design	10 parts x3 operators x2 repeats =60 readings
Repeatability SD	.003 mm
Reproducibility SD	.004 mm
Total study SD	.025 mm
Raw readings / fitted model	Not supplied in this calculation exercise

01 / Define the measurement decision

Eve records the characteristic, range of intended parts, fixture, gauge and appraisers. She asks whether the study represents actual use rather than ten unusually similar parts selected for convenience.

Why: A precise calculation cannot repair an unrepresentative study. Measurement fitness concerns the decisions the system must support.

Evidence / check: The study plan identifies artifacts, operators, conditions and intended use.

02 / Protect repeated observations

The illustrative plan has 60 measurement opportunities. Eve assigns stable part identities and a blinded/randomized order where suitable, with actual observations recorded rather than copied from earlier rounds.

Why: Repeats are meant to reveal measurement variation, not recall of the previous reading. The design is an example, not a mandated sample size for every measurement system.

Evidence / check: A measurement schedule distinguishes part, operator and repeat.

03 / Combine supplied variance components

She squares the SDs, adds .000009 and .000016mm², then takes the square root:.005 mm. She does not add standard deviations directly.

Why: Independent component variances add under the stated model. Their square root returns the result to measurement units.

Evidence / check: Combined gauge variance .000025mm² and SD .005 mm.

04 / Label the two denominators

Gauge SD divided by total SD is .005/.025=.20 or 20%. Gauge variance divided by total variance is .000025/.000625=.04 or 4%.

Why: The two percentages answer different questions and are mathematically consistent. A common study-variation multiplier cancels when applied to both numerator and denominator.

Evidence / check: The report labels percent of total SD separately from percent of total variance.

05 / Interpret fitness with the missing context

Eve requests the fitted-model details, representative data and applicable decision criteria. She also considers bias, resolution, stability and other measurement effects beyond repeatability/reproducibility.

Why: A small variance ratio alone does not establish every aspect of measurement fitness. Calibration status and repeatability are related evidence, not interchangeable approvals.

Evidence / check: The conclusion reports the supplied arithmetic and lists the remaining fitness evidence.

Completed measurement-component record

Quantity	Calculation	Result
Gauge variance	$.003^2 + .004^2$	$.000025 mm^2$
Gauge SD	$\sqrt{.000025}$	.005 mm
Share of total SD	.005/.025	20%
Share of total variance	$.005^2/.025^2$	4%
Fitness decision	Applicable requirements and complete study	Not established here

The selected parts cover almost no process range

The ten study parts were all chosen from one narrow group, unlike the range encountered in normal inspection.

Decision

Review and redesign the representative-artifact selection before interpreting the ratio as evidence for normal production decisions. Preserve the original study scope.

Reasoning

The denominator and apparent relative variation depend on the study population. A ratio from an artificially narrow range can be misleading for the intended use.

What would change the decision?

The revised plan explains how selected artifacts represent the measurement task.

Practise with a changed case

Reconcile a changed set of components

New supplied estimates are repeatability SD .006 mm, reproducibility SD .008 mm and total SD .050 mm. A trainee reports combined SD .014 mm.

Component	Supplied SD
Repeatability	.006 mm
Reproducibility	.008 mm
Total	.050 mm

Your task

1. Calculate combined gauge SD using variances.
2. Calculate the two labelled percentages.
3. Identify one missing study-design and one missing fitness consideration.

Use the next page to record your reasoning before reading the answer.

Your practice worksheet

Reconcile a changed set of components

Component squares

Combined variance and SD

Denominator labels

Design scope

Decision limitation

Complete your reasoning before turning to the answer. Use the separate learner workbook for group practice.

Check your reasoning and transfer it

1. Gauge variance=.000036+.000064=.000100mm², so SD=.010 mm. The SD share is .010/.050=20%; variance share is .0001/.0025=4%.

2. The .014 result incorrectly adds SDs. Representative parts/appraisers and a suitable analysis model still need evidence, as do relevant bias, resolution, stability or decision criteria.

Suggested completed record

Metric	Result	Unit or denominator
Combined gauge SD	.010	mm
SD share	20%	Total SD
Variance share	4%	Total variance

Plausible wrong turns

1. Standard deviations do not add as independent variances do.
2. A supplied component calculation is not an executed measurement study.

Evidence of a sound answer

1. Calculate in squared units and return to mm.
2. Label both percentages.
3. Separate arithmetic from measurement approval.

Take the learning back to work

Commitment	Agreed follow-through
Owner	Measurement-system owner
Record	Study plan, raw readings, model, component labels and fitness decision
Review	Before use for a new decision and after material method changes
Verification evidence	Representative design and suitable measurement evidence
If unresolved	Improve the method or study design and reassess rather than changing percentage labels to appear acceptable.

Help someone else apply the method

Prepare

1. Measurement schedule
2. Component cards
3. Calculator

Minutes	Activity and coaching prompt
5	Describe a repeat How would memory of a reading bias the exercise?
8	Combine components Why square before adding?
10	Work the changed estimates How can 20% and 4% agree?
5	Debrief fitness What can this ratio not tell us?

Debrief

1. Ask learners to state the denominator aloud.
2. Challenge the idea that one example design is a universal minimum.

Individual or remote practice

Draw a units column beside every intermediate calculation.

Connect the method and check its boundaries

Before application

1. Representative parts and appraisers
2. A design suitable for repeated or destructive measurement

Outside this lesson

1. A universal acceptance percentage
2. All sources of bias, linearity and stability error

NIST: Gauge R&R

NIST: Gauge R&R

Measurement characterization covers repeatability, reproducibility, stability, bias, resolution, linearity and other error sources.

Public primary-source summary; underlying paid standards/forms are not reproduced.

NIST: Gauge study design

NIST: Gauge study design

A measurement study needs considered choices of artifacts, operators, gauges and measurement levels.

Public primary-source summary; underlying paid standards/forms are not reproduced.

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