History of Measurement Systems with Applications

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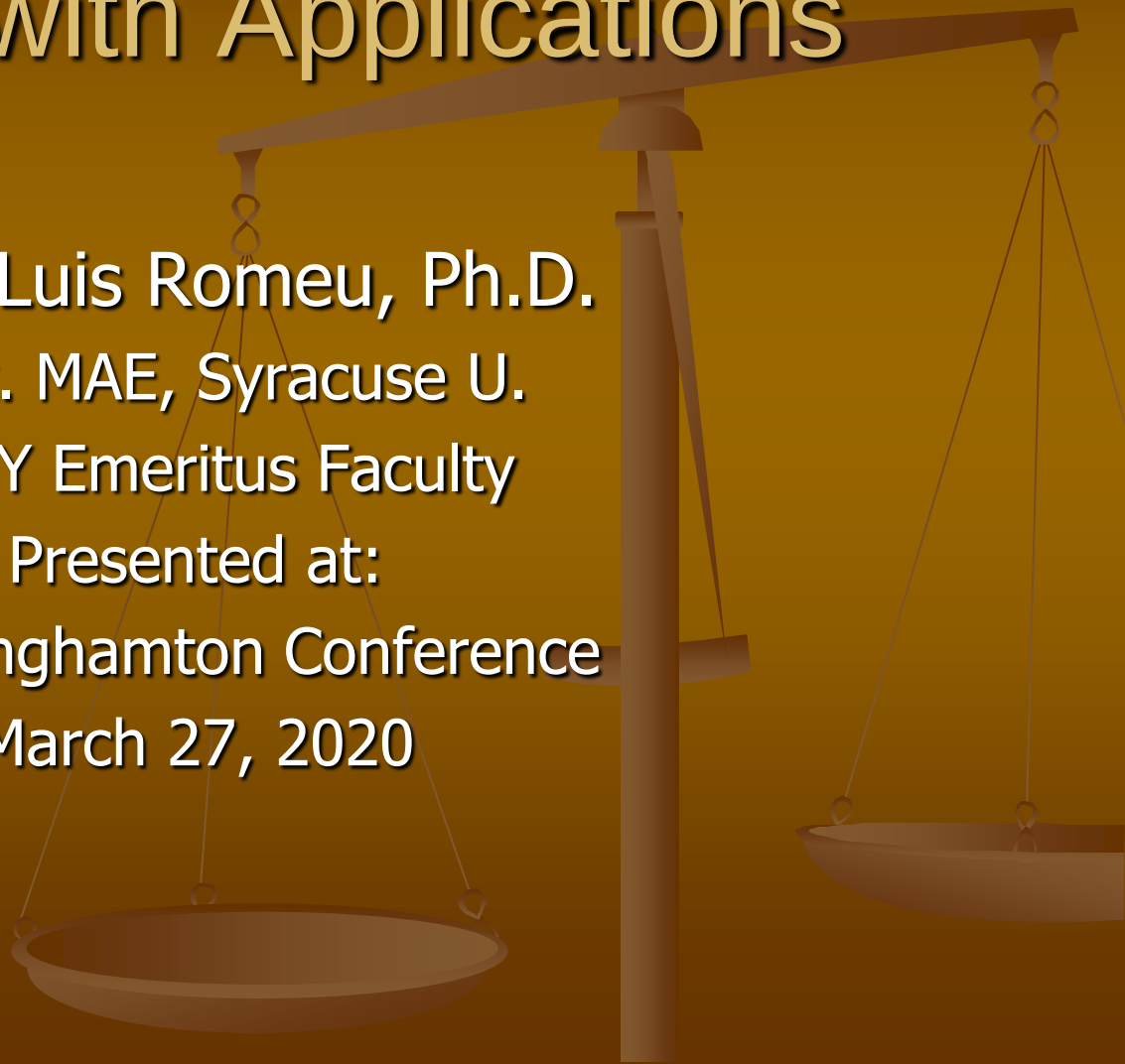


Borrowed from the Presentation: Measurement & Traceability

Minnesota Department of Commerce

Weights and Measures Division

Carol Hockert, Director

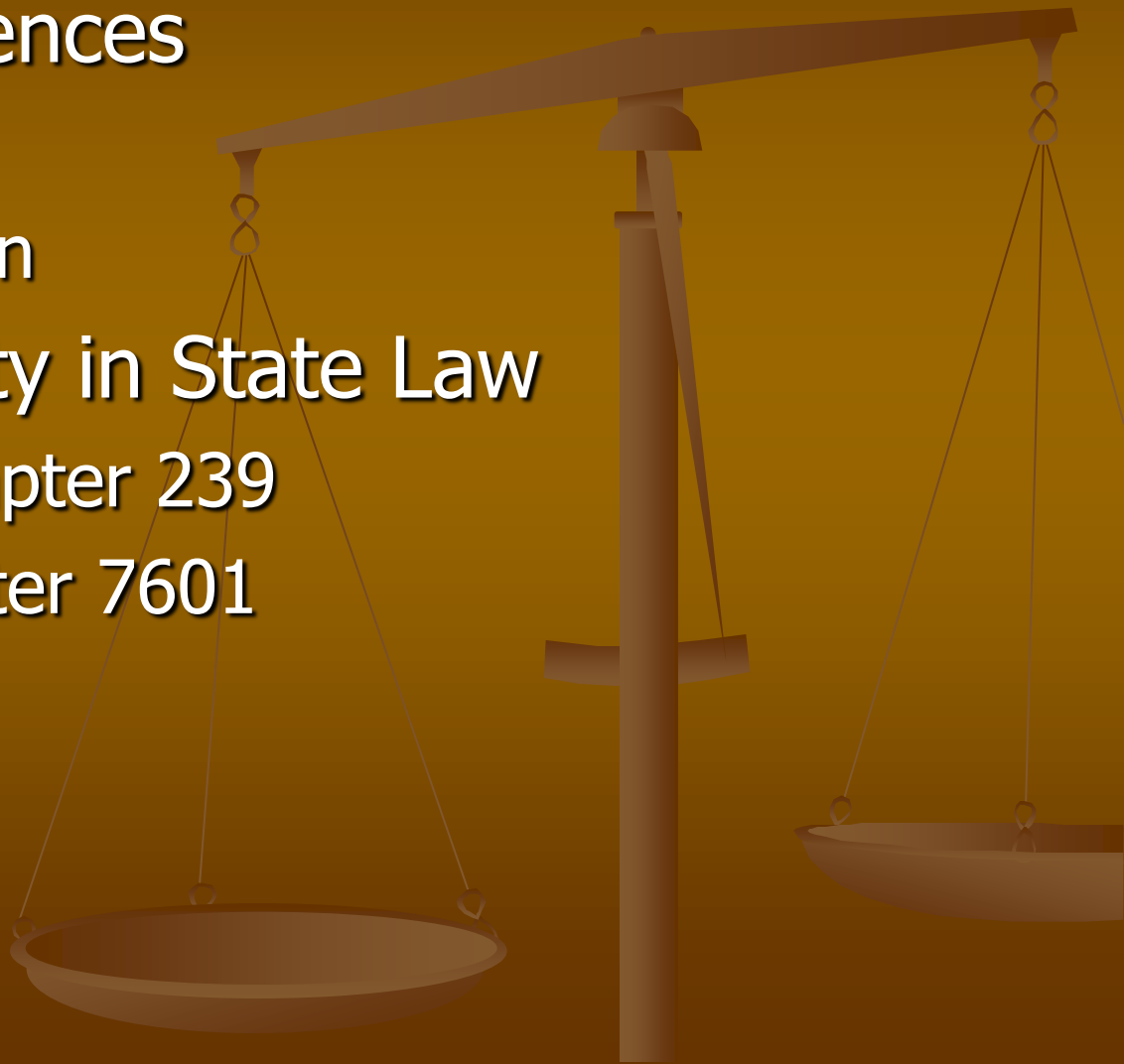
With Acknowledgements to:

Georgia Harris, National Institute of Standards and Technology

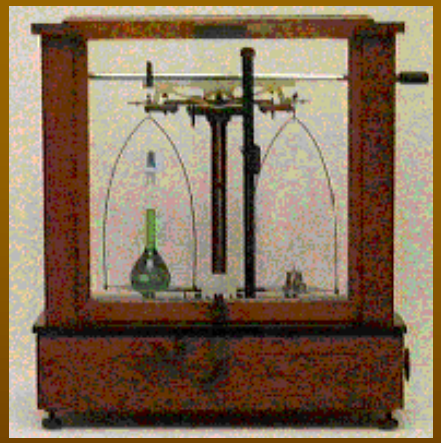
Elizabeth Gentry, Oklahoma Bureau of Standards

Weights and Measures

- Historical References
  - Biblical
  - U.S. Constitution
- Current Authority in State Law
  - MN Statute Chapter 239
  - MN Rules Chapter 7601



For Commerce to Extend Beyond Barter



- Currency one can trust

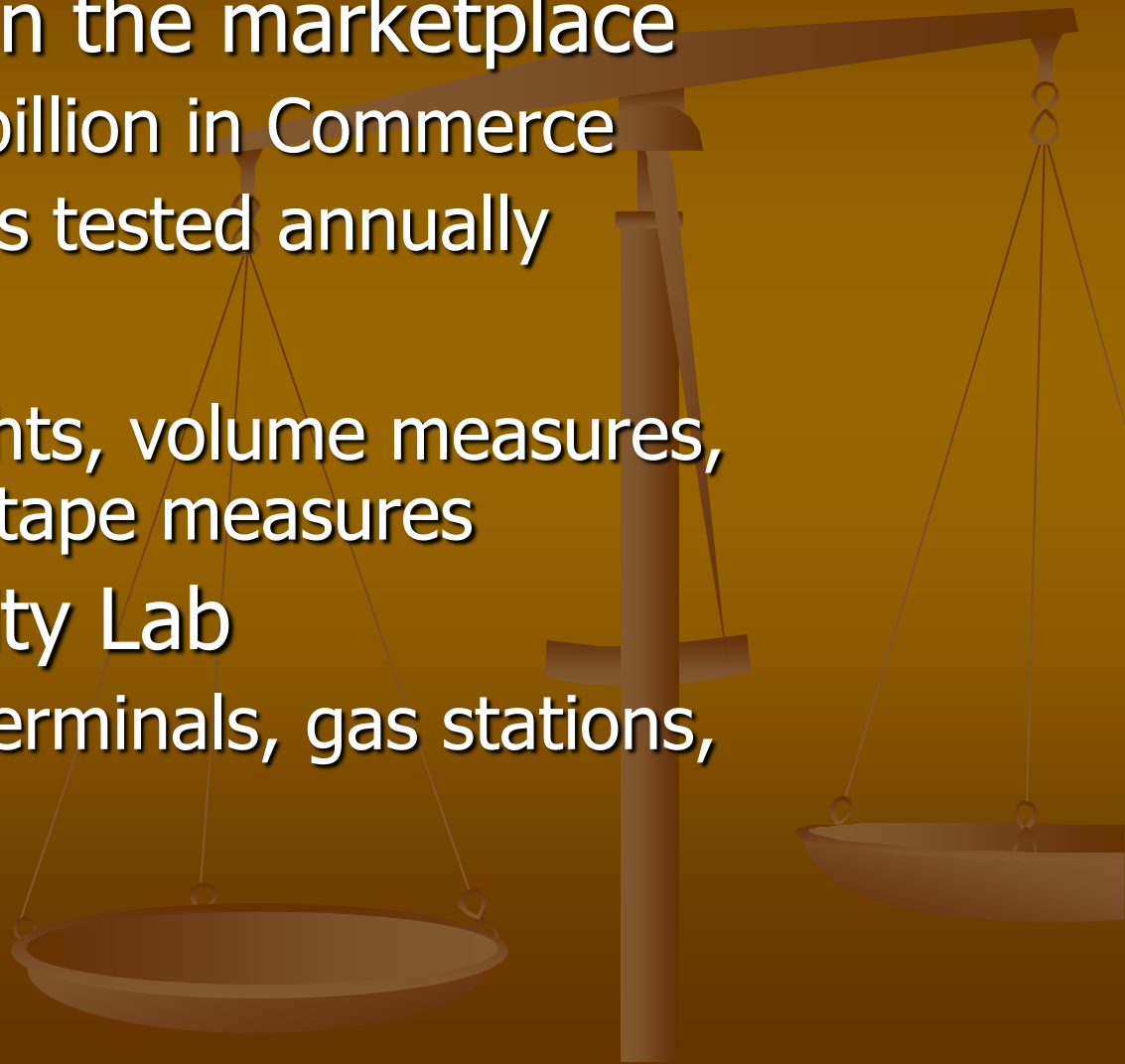
  and

- Measurements one can trust

  are required

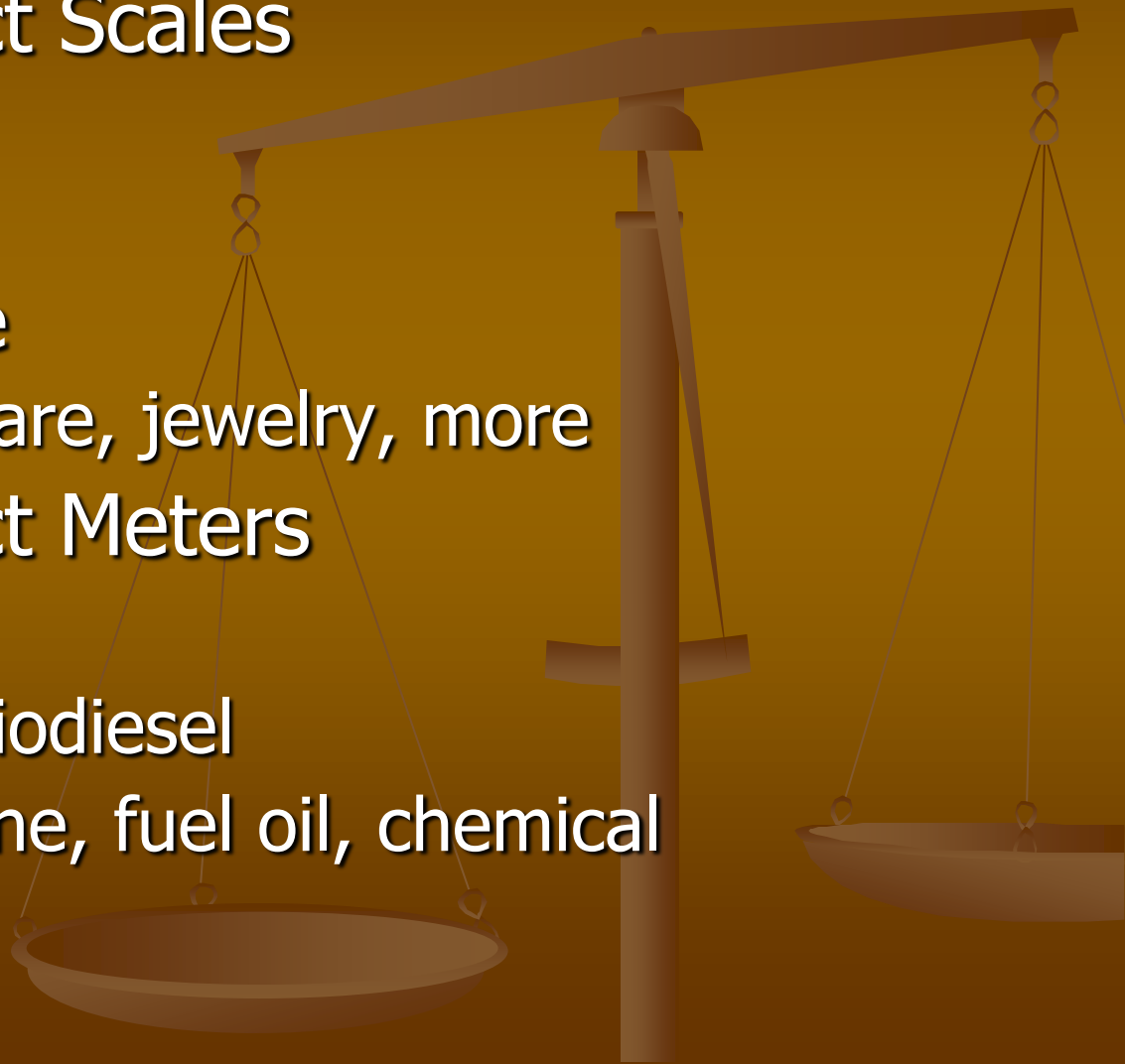
Weights & Measures

- Ensures equity in the marketplace
  - Impacts >$25 billion in Commerce
  - ~70,000 devices tested annually
- Metrology Lab
  - Calibrates weights, volume measures, thermometers, tape measures
- Petroleum Quality Lab
  - Samples from terminals, gas stations, complaints



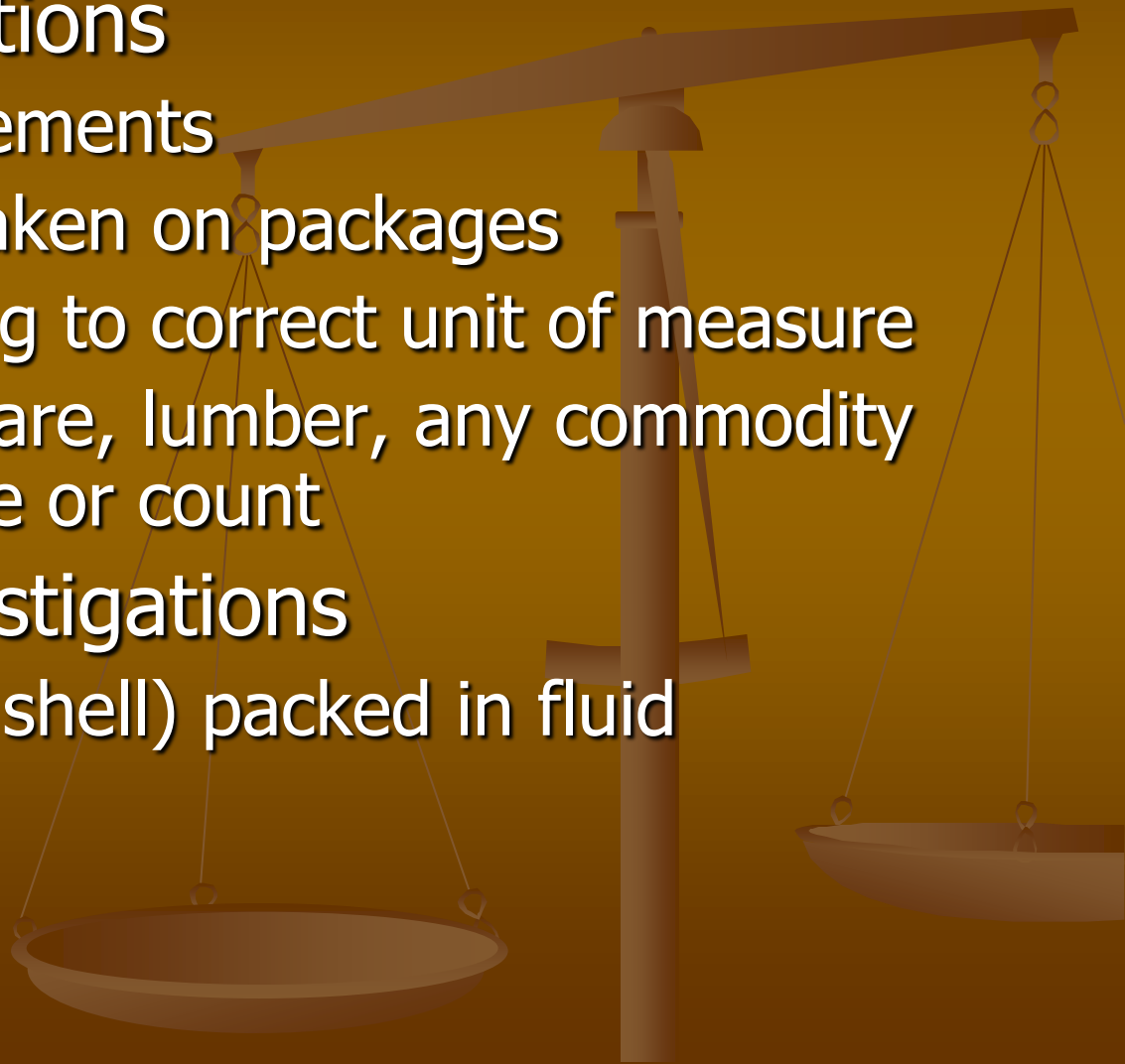
Weights and Measures

- Test and Inspect Scales
  - Grain elevators
  - Livestock
  - Railway, vehicle
  - Grocery, hardware, jewelry, more
- Test and Inspect Meters
  - Gasoline, diesel
  - Milk, ethanol, biodiesel
  - Jet fuel, kerosene, fuel oil, chemical



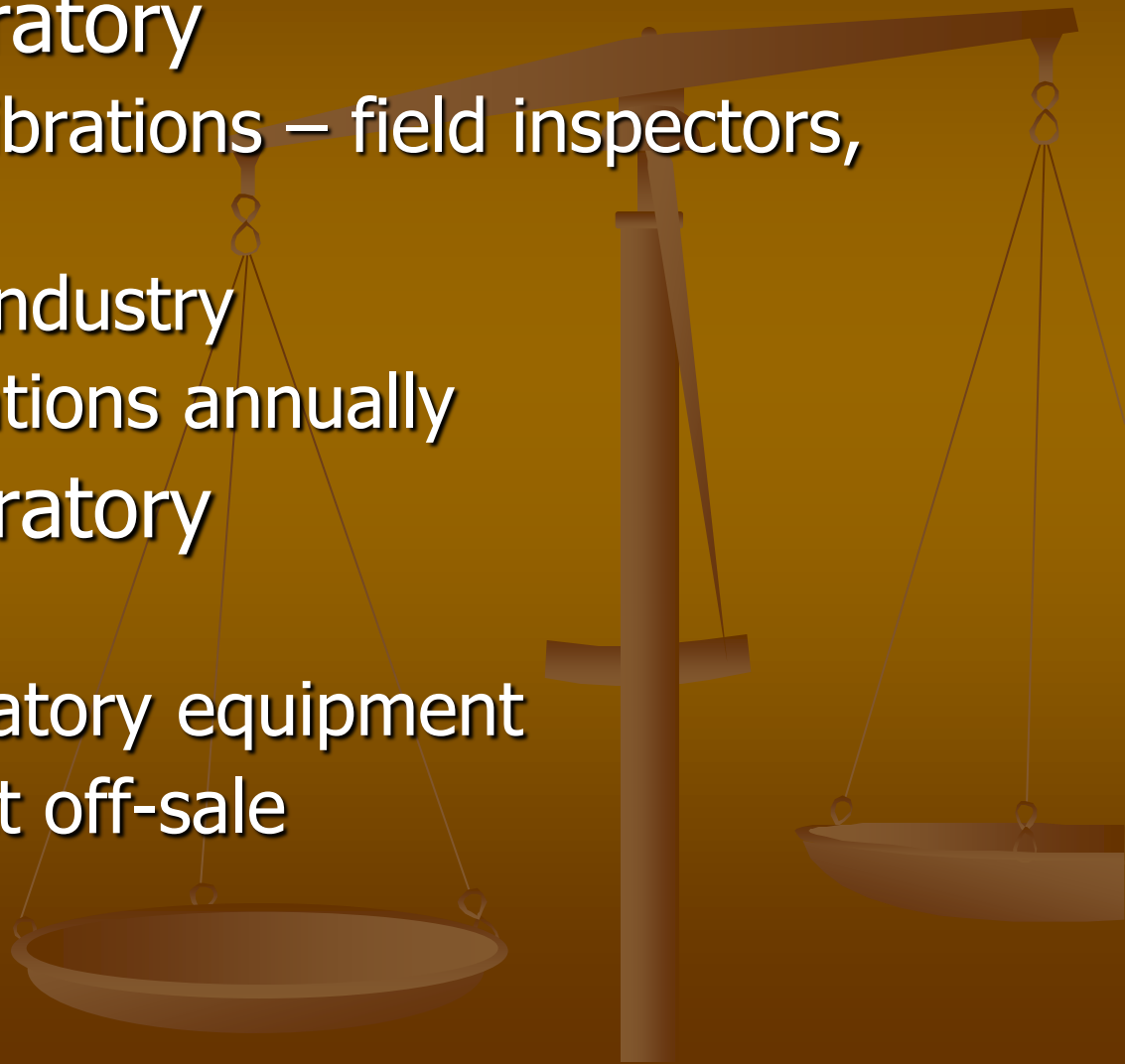
Weights and Measures

- Package Inspections
  - Labeling requirements
  - Accurate tare taken on packages
  - Selling according to correct unit of measure
  - Grocery, hardware, lumber, any commodity sold by measure or count
- Interesting investigations
  - Oysters (out of shell) packed in fluid
  - Milk



Weights and Measures

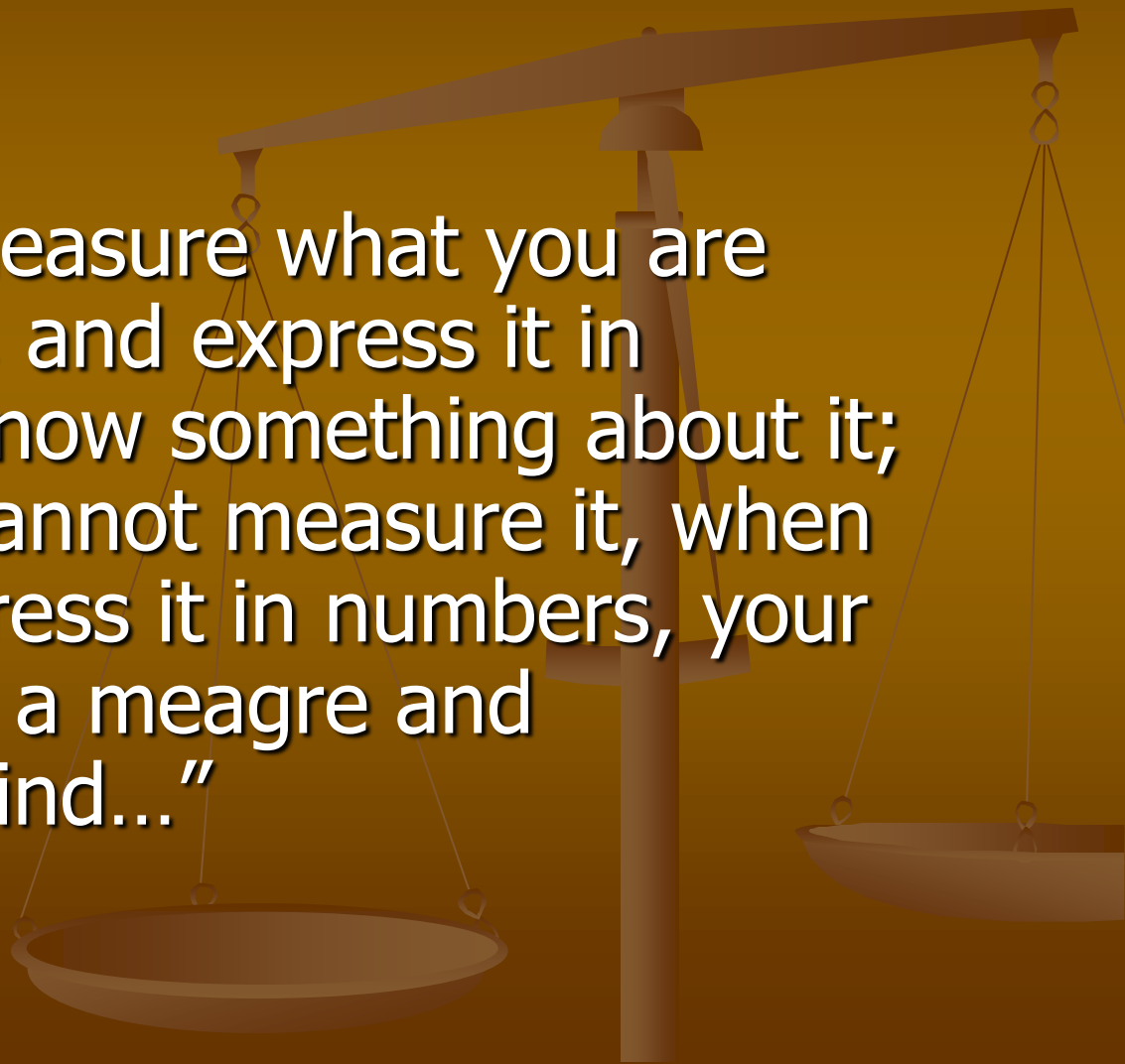
- Metrology Laboratory
  - Commercial calibrations – field inspectors, agents
  - Calibration for industry
  - ~20,000 calibrations annually
- Petroleum Laboratory
  - ASTM tests
  - Analytical laboratory equipment
  - Pull bad product off-sale



Measurement

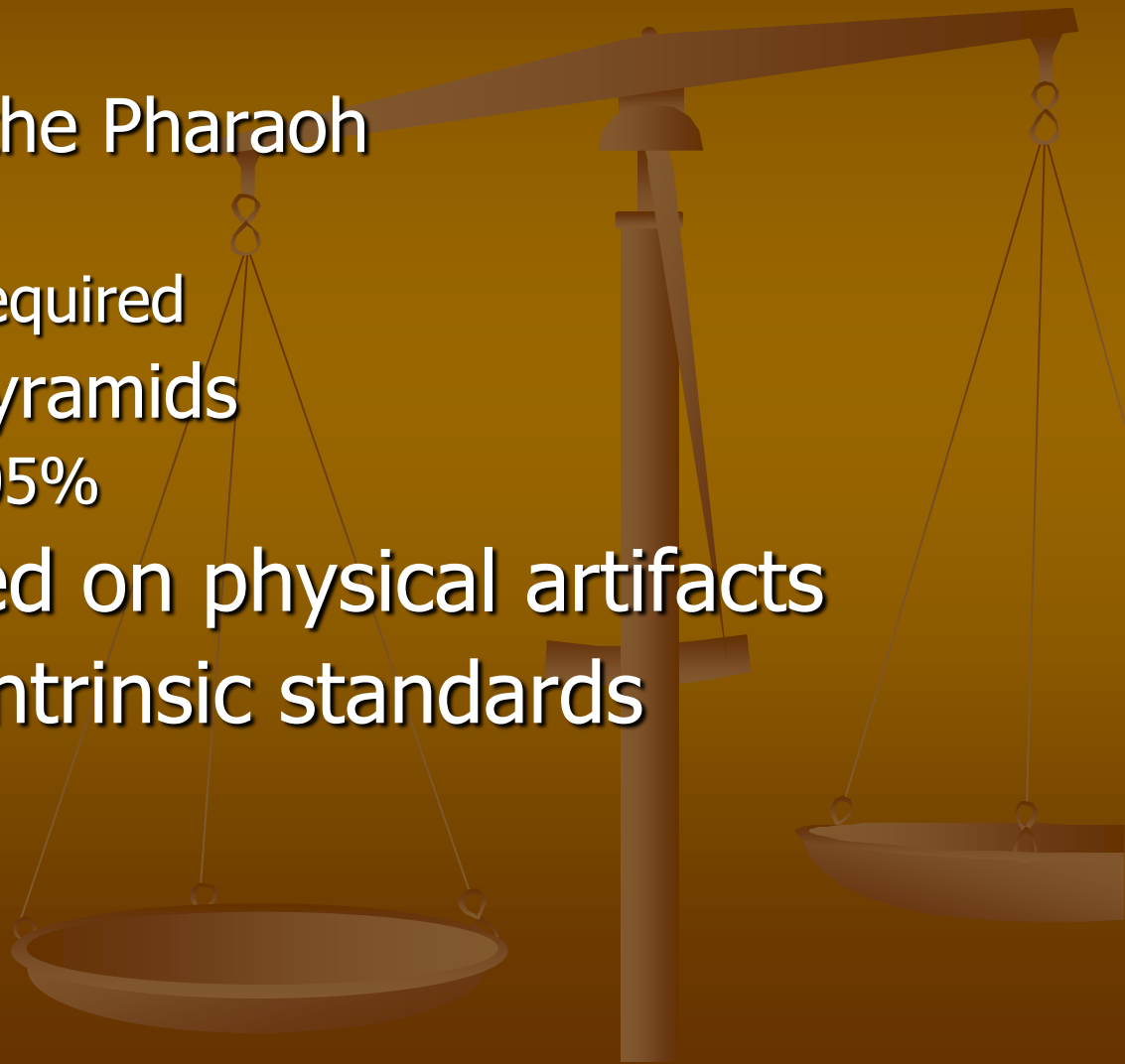
Lord Kelvin said:

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind…"



History of Measurement

- Egyptian Cubit
  - Dependent on the Pharaoh
    - Traceable
    - Recalibration required
  - Used to build Pyramids
    - Accuracy of 0.05%
- Historically based on physical artifacts
- Now based on intrinsic standards
  - Exception?

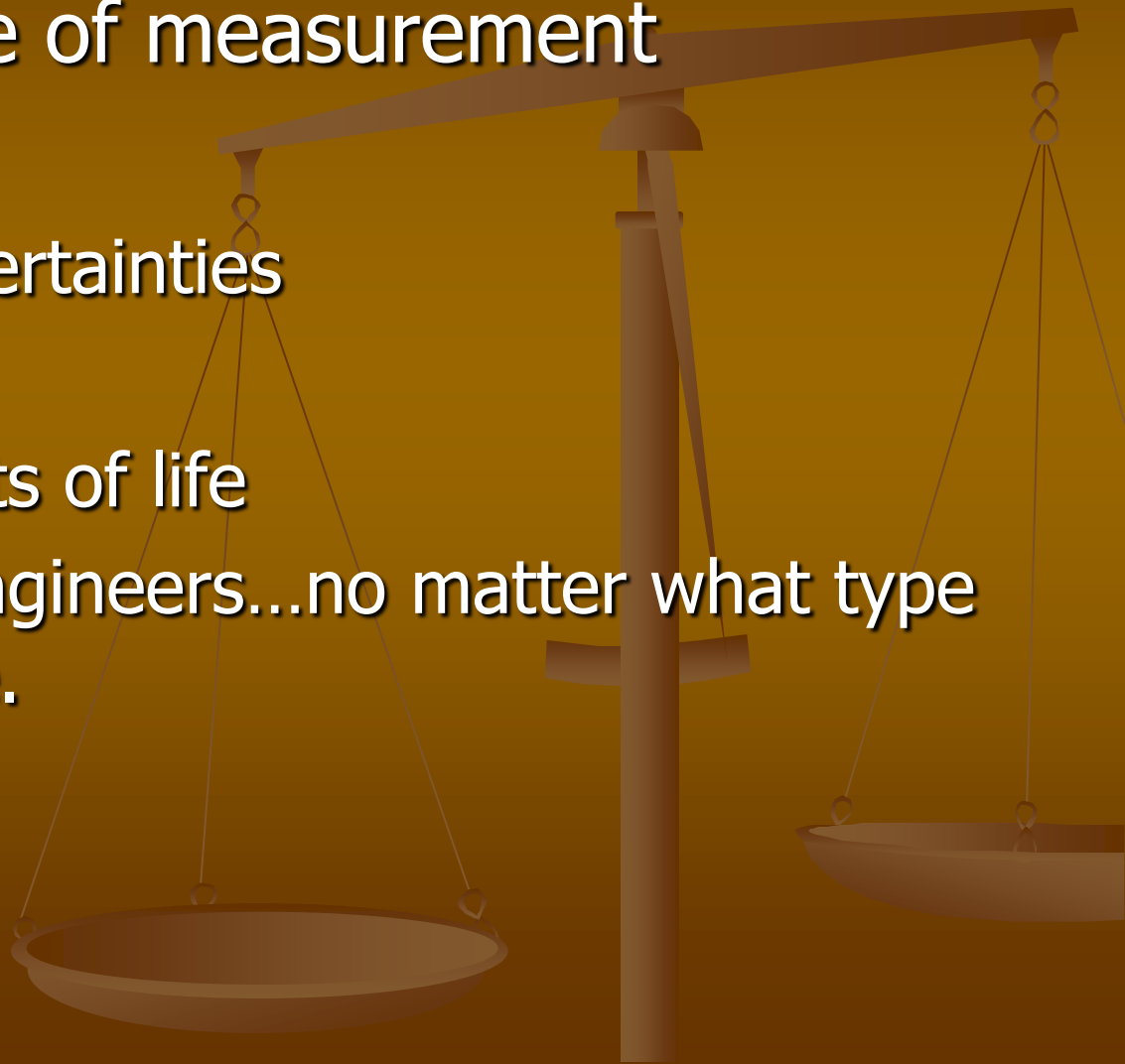


Mass Standards

- Based on the platinum-iridium cylinder locked up in a vault at the International Bureau of Weights and Measures (BIPM)
- Current research conducted
  - Watt Balance
  - Counting atoms (silicon)
  - Neither are as accurate as the current standard
- Most still rely on calibrated pieces of metal

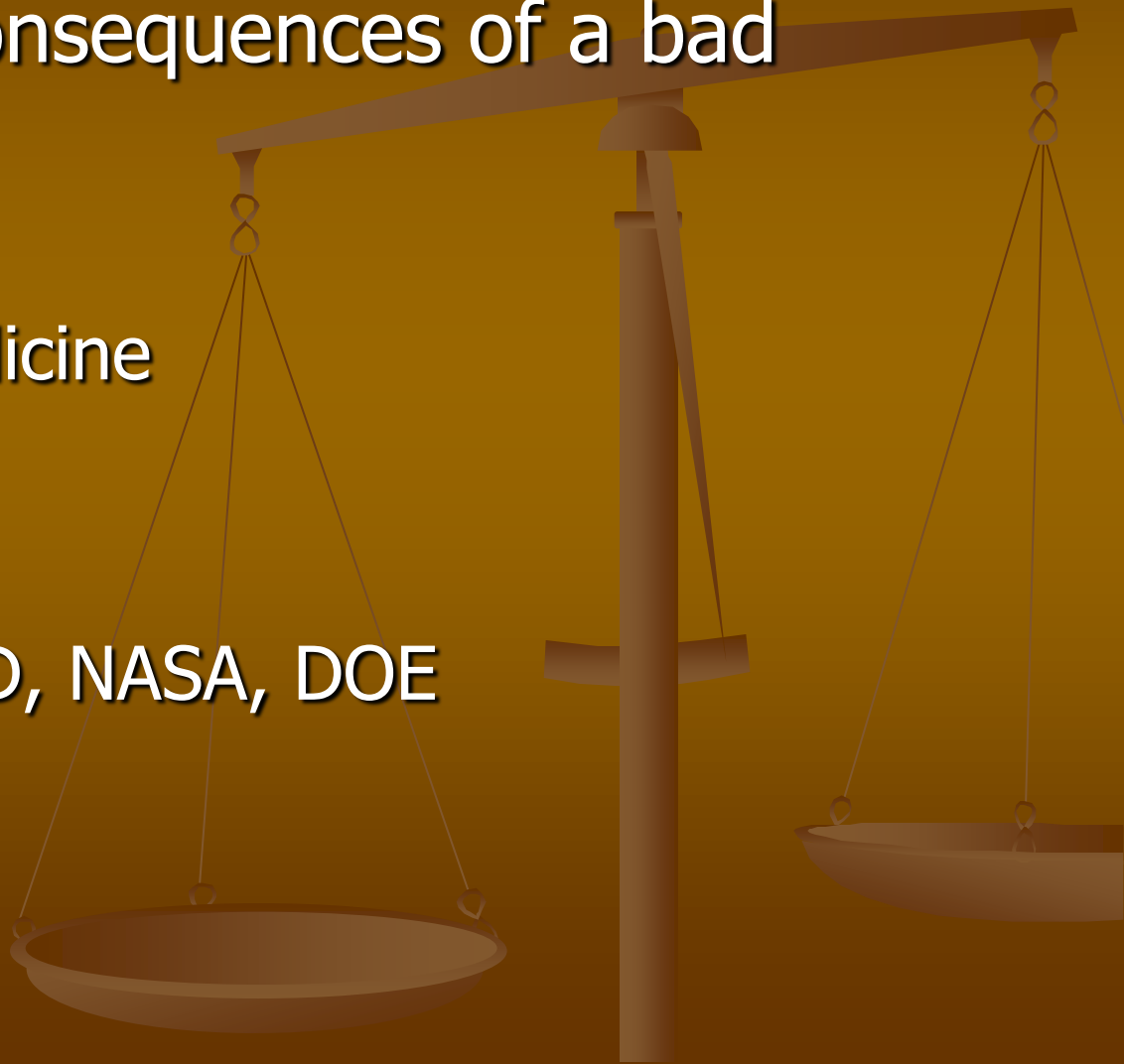
Metrology

- Study or science of measurement
- Measurements:
  - Associated Uncertainties
  - Traceable
  - Affect all aspects of life
  - Important to engineers…no matter what type of job you have.
- SI base units



Measurements

- What are the consequences of a bad measurement?
  - Commerce
  - Health and Medicine
  - Manufacturing
  - Technology
  - Aerospace, DOD, NASA, DOE



Good measurements

- What accuracy do you need?
  - Parts per million
  - Parts per hundred
- How precise is your measurement?
  - Repeatability
  - Reproducibility
- Traceability

Traceability

- International Vocabulary of Metrology (VIM) Definition:

  "Property of the result of measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties."

Criteria for Traceability[1]

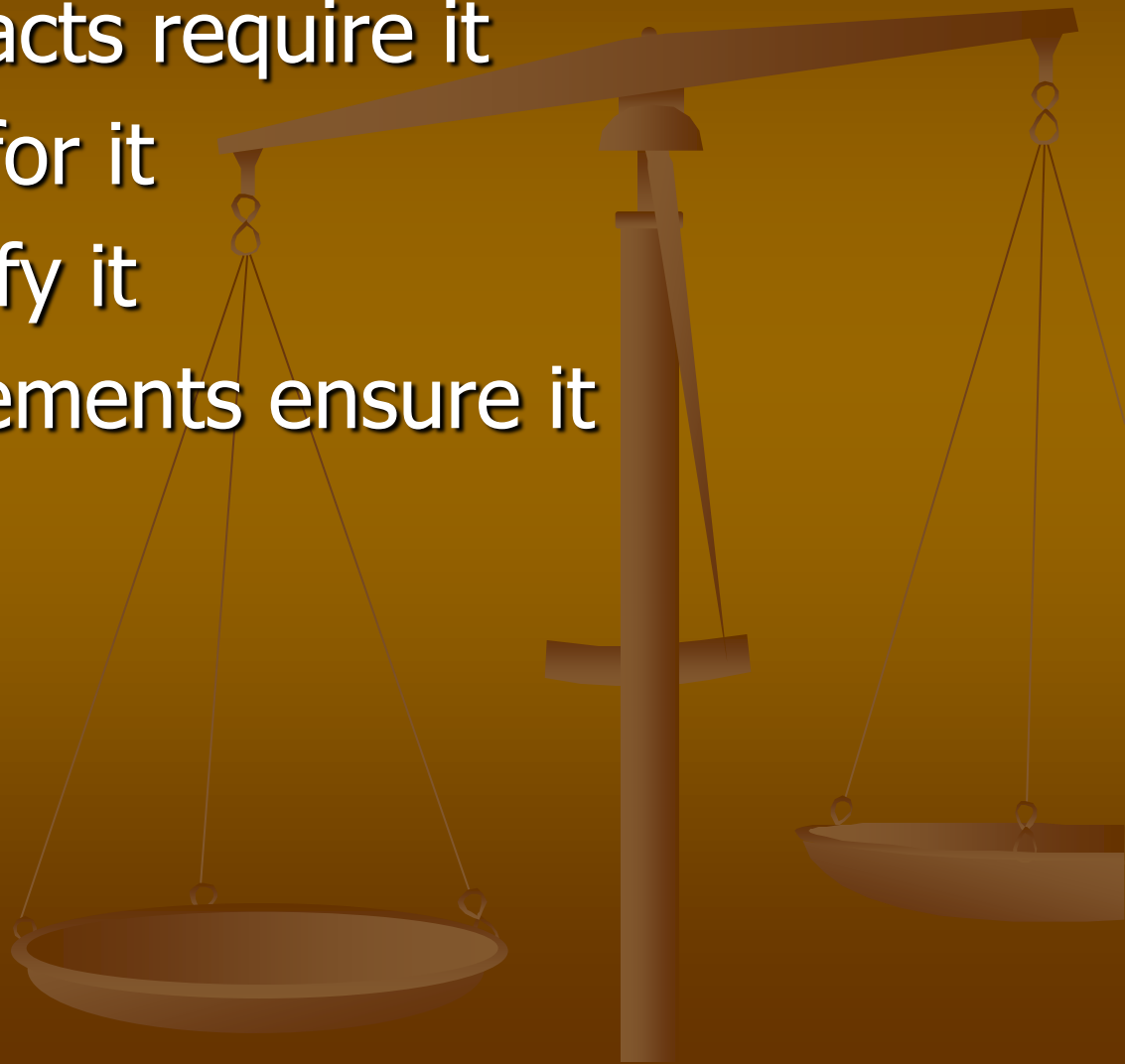
Result of a measurement or the value of a standard

1. Unbroken chain of comparisons
2. Stated Uncertainties
3. Documented
4. Competence
5. Reference to national or international standards or SI Units
6. Periodic Verification
7. Measurement Assurance

[1] NIST IR 6969, GMP 13, based on ILAC G2 with additional requirements

Traceability – Why do we need it?

- Laws and contracts require it
- Customers ask for it
- Standards specify it
- Quality measurements ensure it



Measurement Traceability for Weights & Measures

International Standards (SI Units)

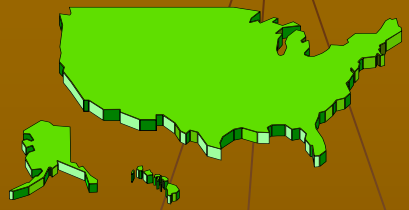
NIST

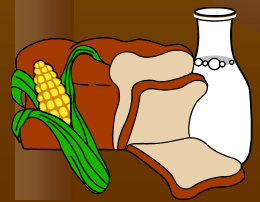
State Laboratory Standards

State Field Standards

Devices

User/ Consumer





An unbroken chain from international standards to the market.

Uncertainty Formula

- Combined uncertainty

$$u_c = \sqrt{u_s^2 + s_p^2 + u_d^2 + u_o^2}$$

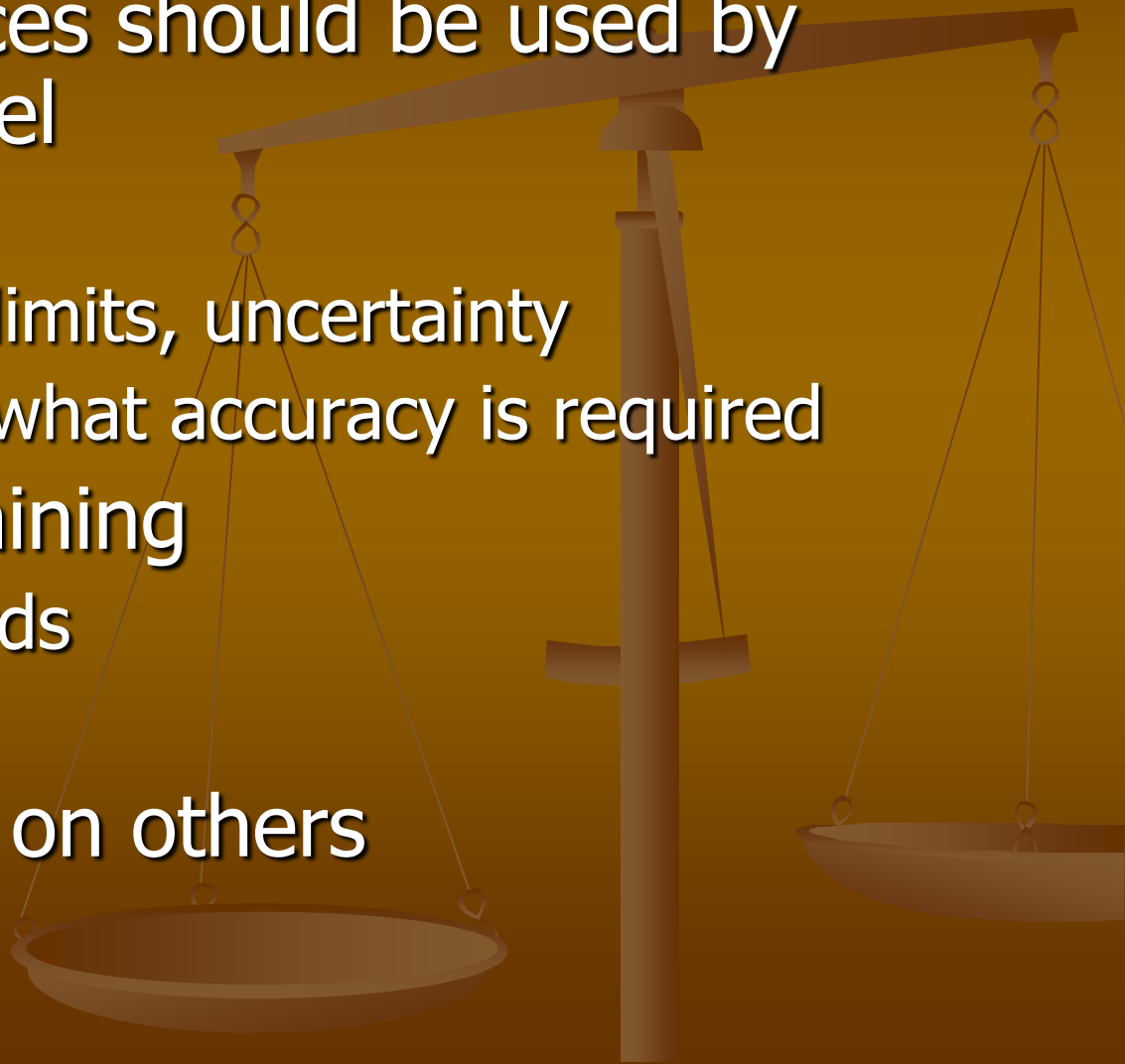
- Expanded uncertainty (what is reported) 95% or 99% confidence interval

$$U = u_c \times k$$

where $k = 2$ or $k = 3$

Competence

- Measuring devices should be used by trained personnel
  - Procedures
  - Understanding limits, uncertainty
  - Understanding what accuracy is required
- Documented training
  - Personnel records
  - Training file
- Interdependent on others



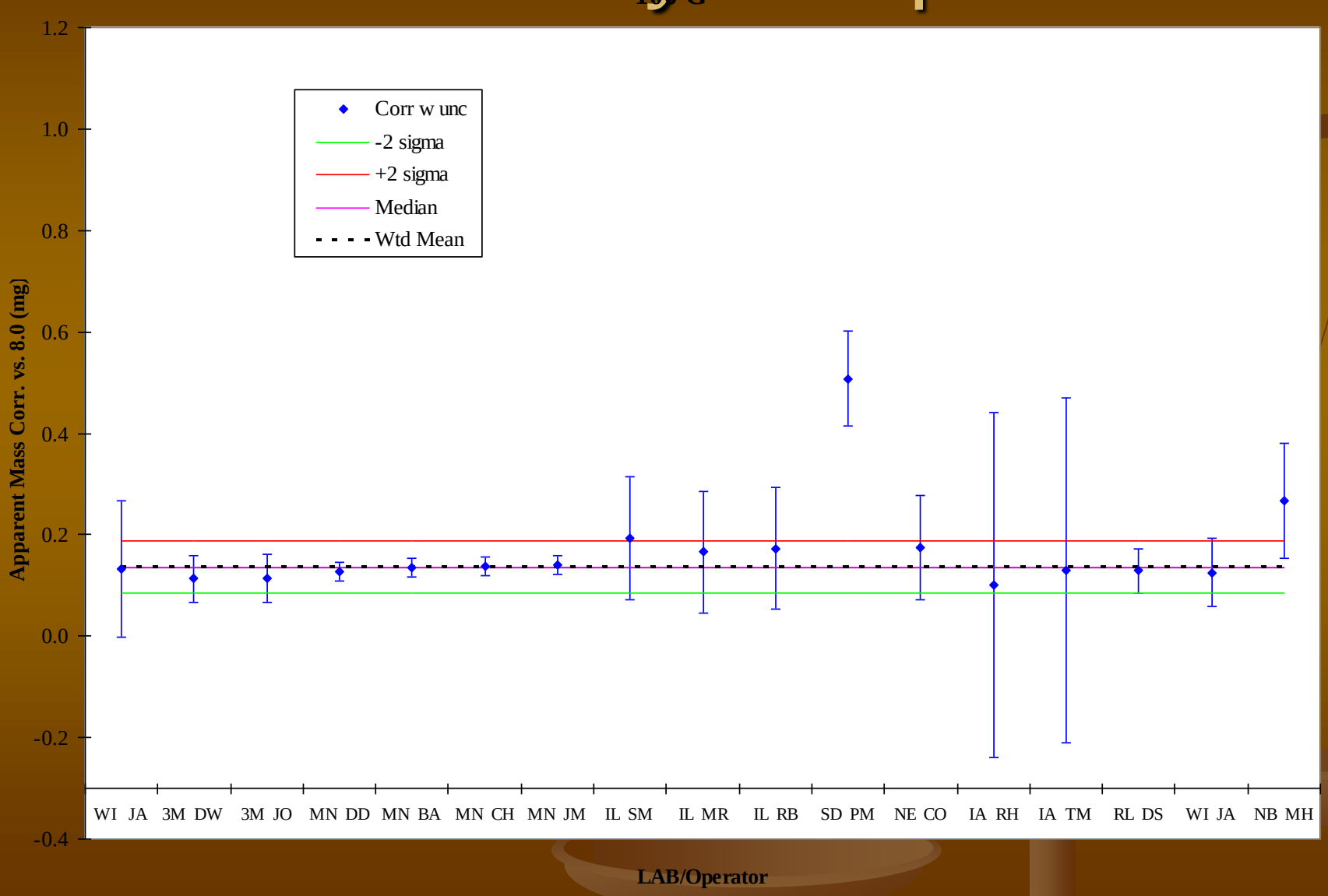
Periodic Verification

- Calibrate and then Recalibrate at specified intervals
  - Dependent on time and use
  - Set by the user of the device or by law
- Commerce requires annual verification
- Volumetric glassware may have 10 year cycle
- Thermocouples may have 3 month cycle
- Consequences of long intervals

Measurement Assurance

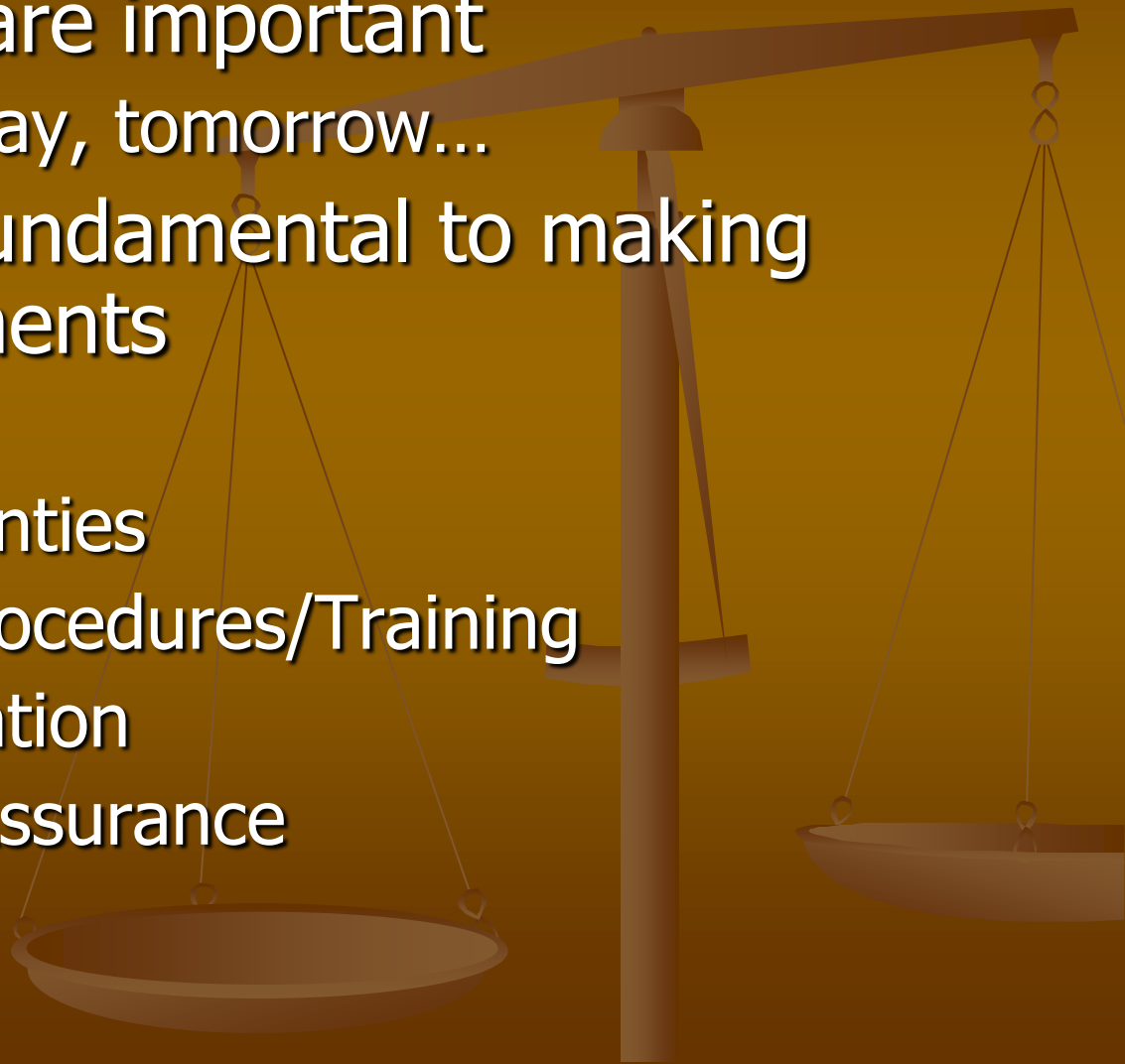
- Quality Control
  - Check standards
  - Interlaboratory comparisons (Round robins)
- Control charts
  - Standards
  - Processes

Interlaboratory Comparisons

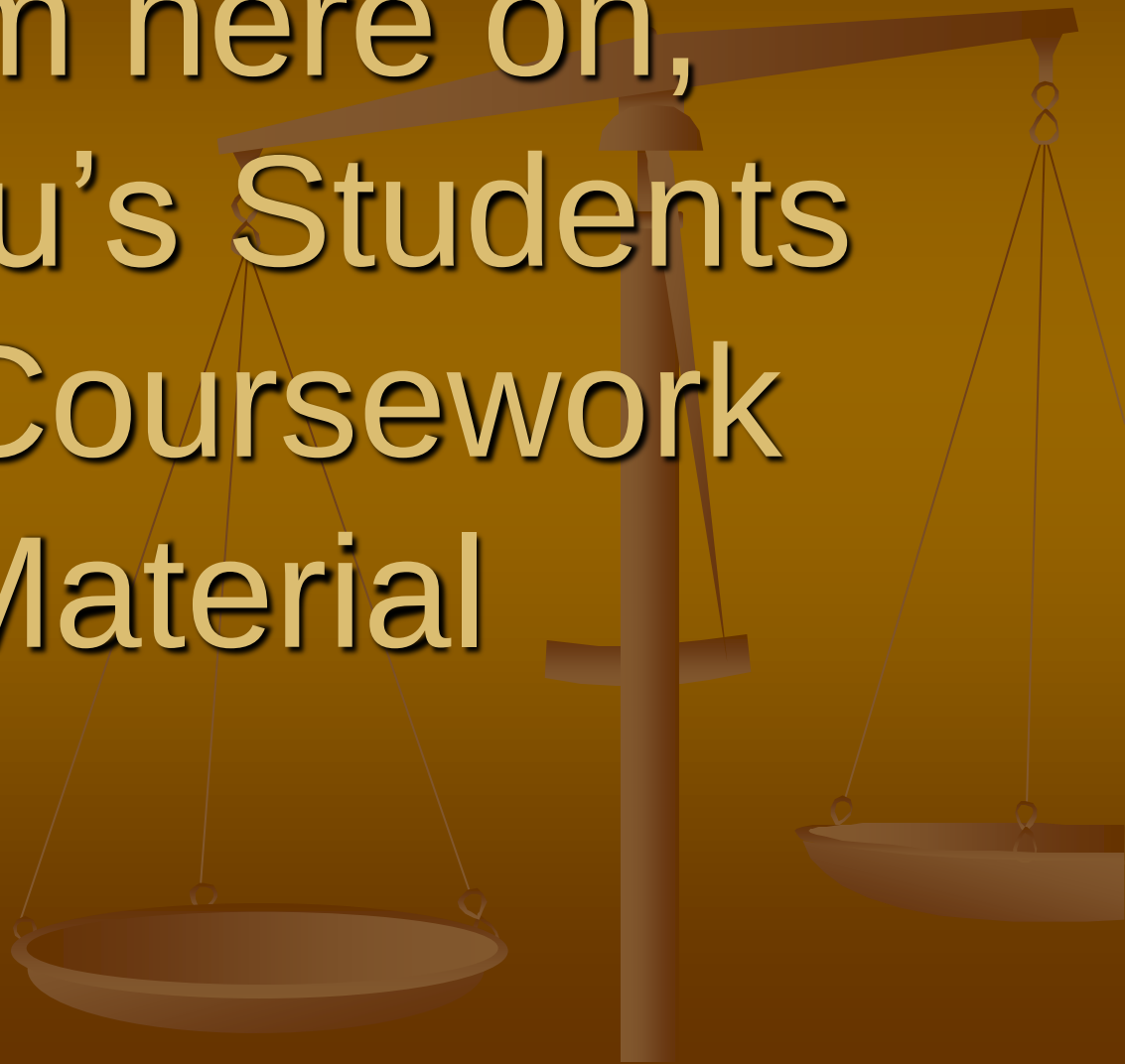


Summary

- Measurements are important
  - Historically, today, tomorrow…
- Traceability is fundamental to making good measurements
  - Link to SI units
  - Stated Uncertainties
  - Documented Procedures/Training
  - Periodic Verification
  - Measurement Assurance



From here on, Romeu's Students and Coursework Material



Some Examples of Gage R&R

- Some Definitions
- Quantitative Analysis
- Qualitative Analisis
- By Minitab Stats SW

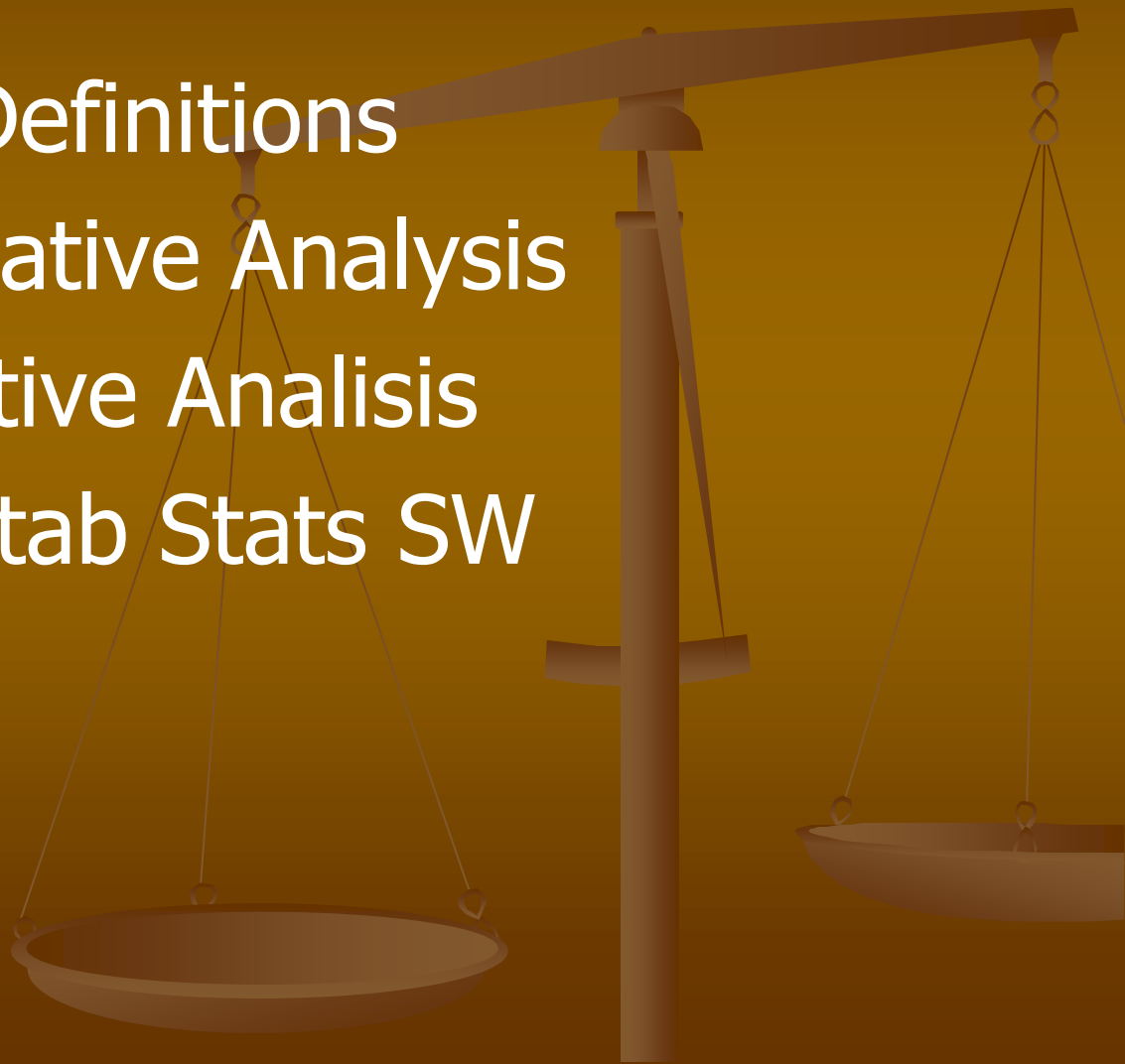


Fig. 13-7

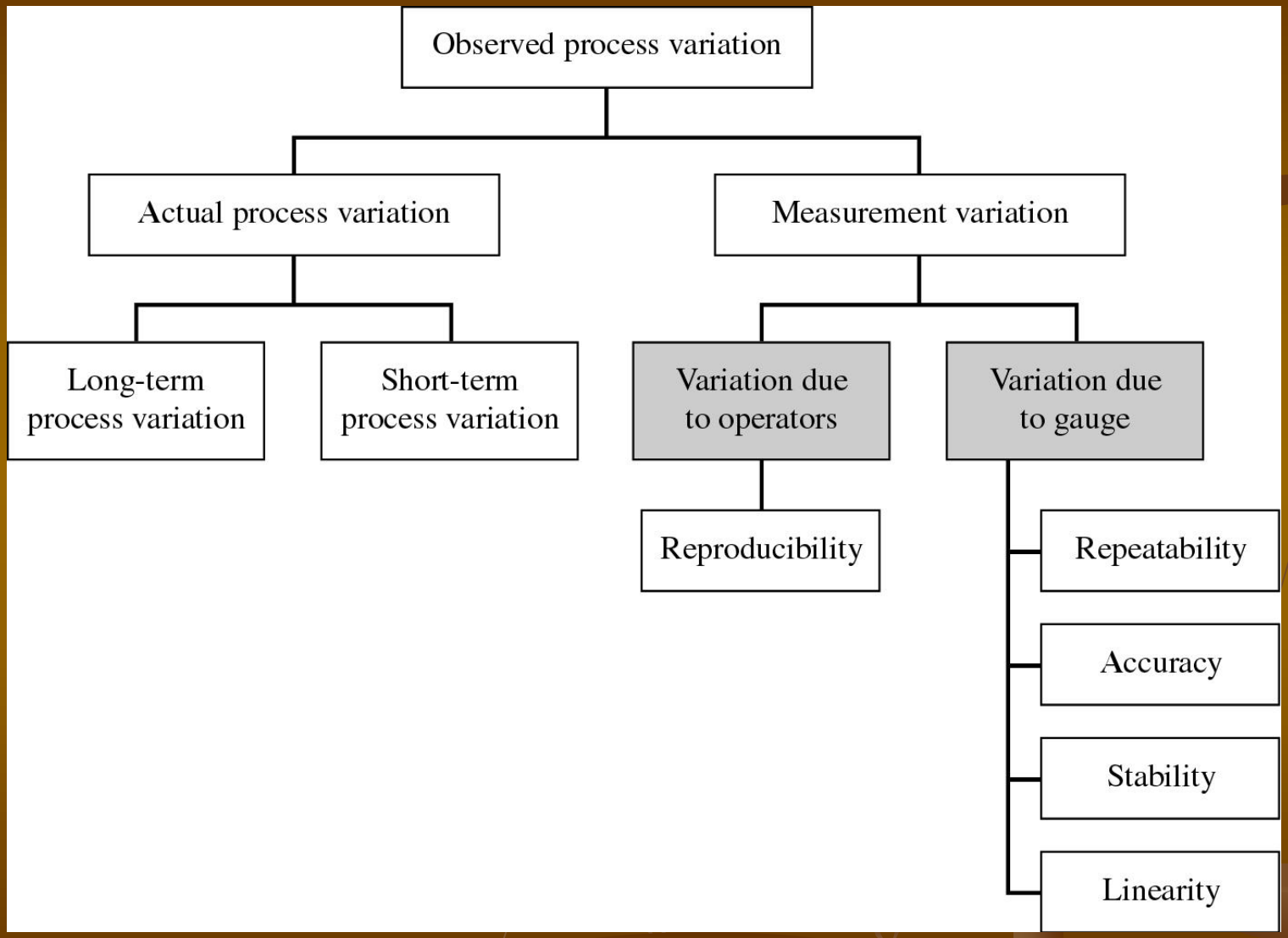

Observed process variation
Actual process variation
Measurement variation
Long-term process variation
Short-term process variation
Variation due to operators
Variation due to gauge
Reproducibility
Repeatability
Accuracy
Stability
Linearity

Fig. 15-2a

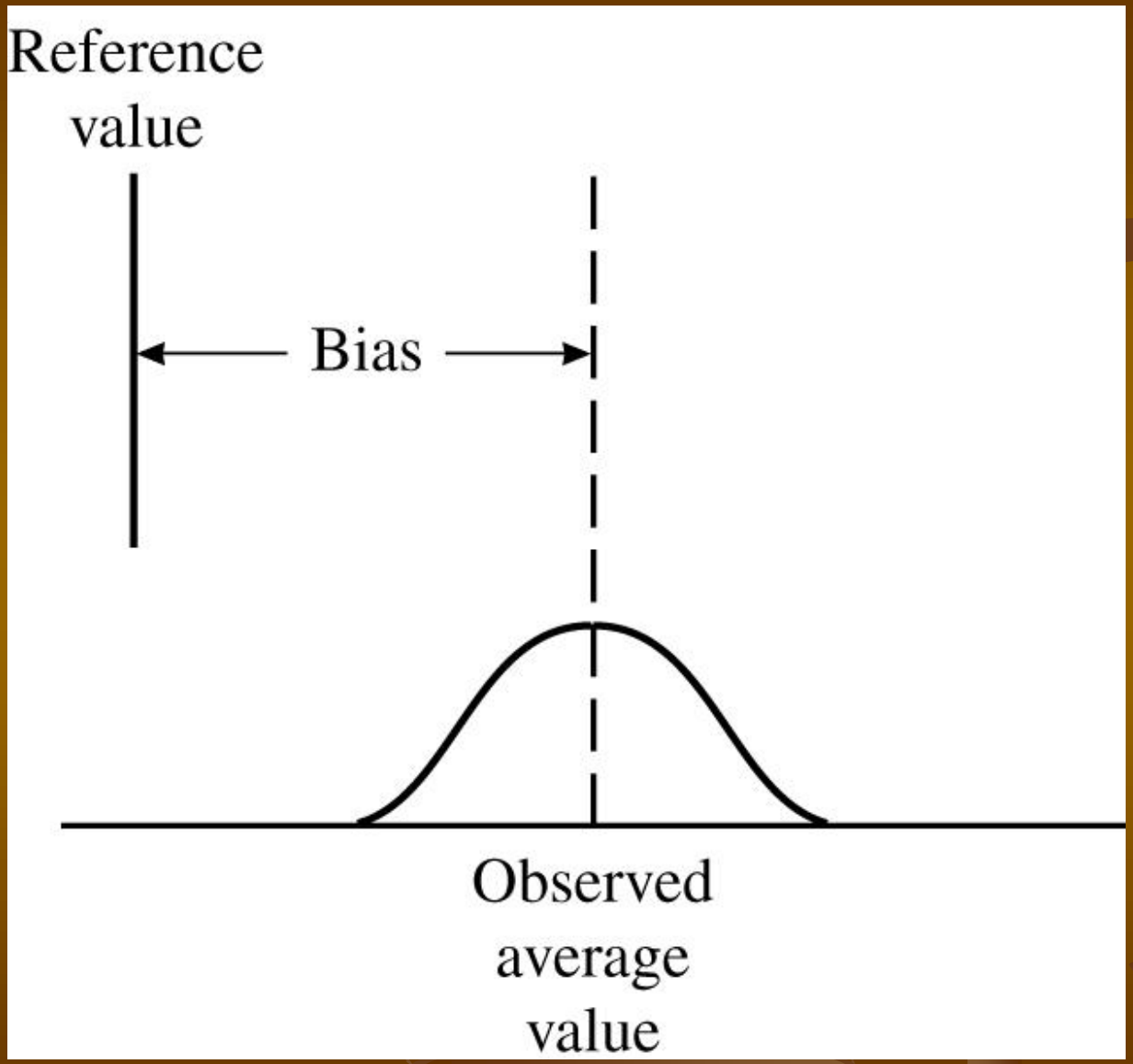


Fig. 15-2b

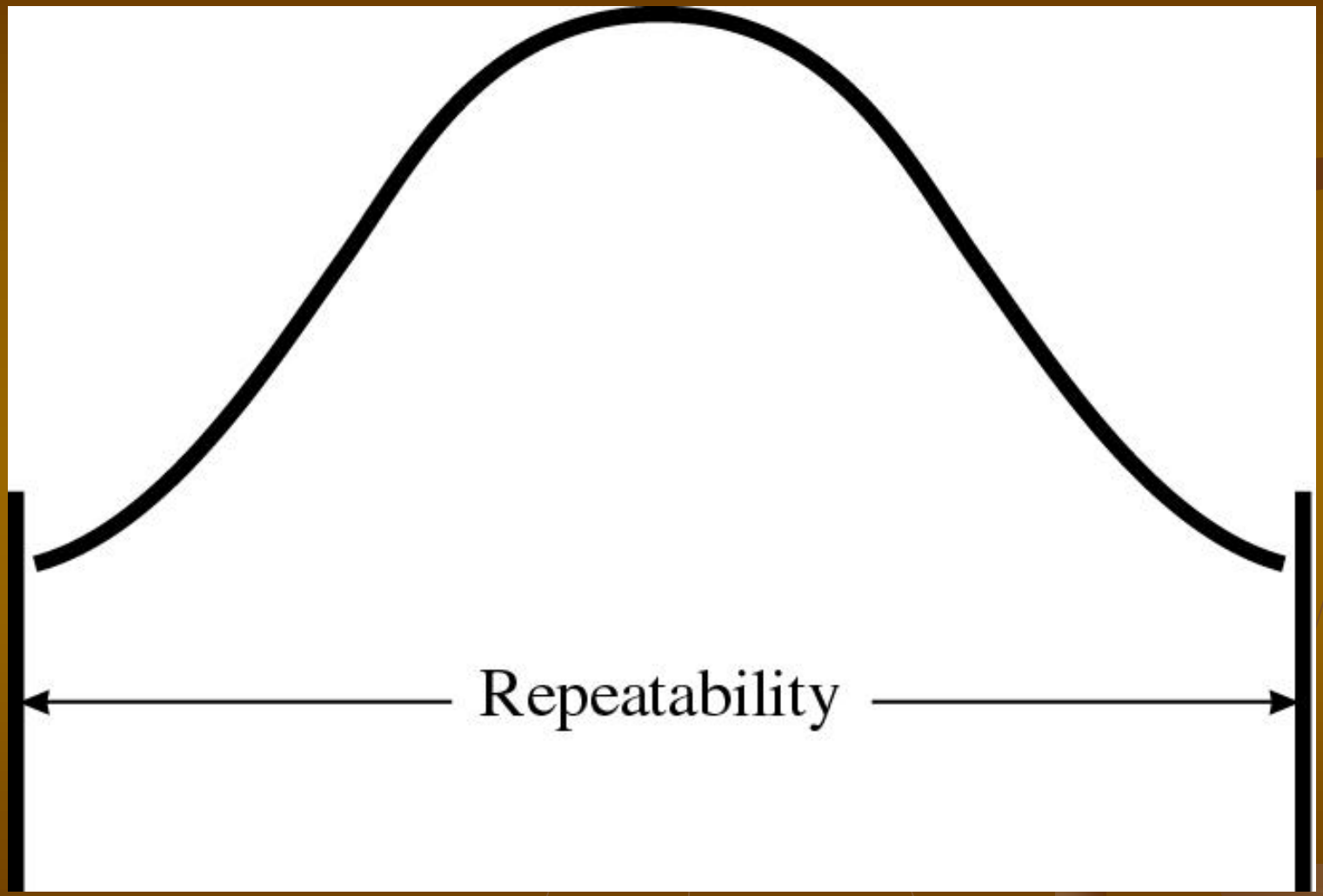


Fig. 15-2c

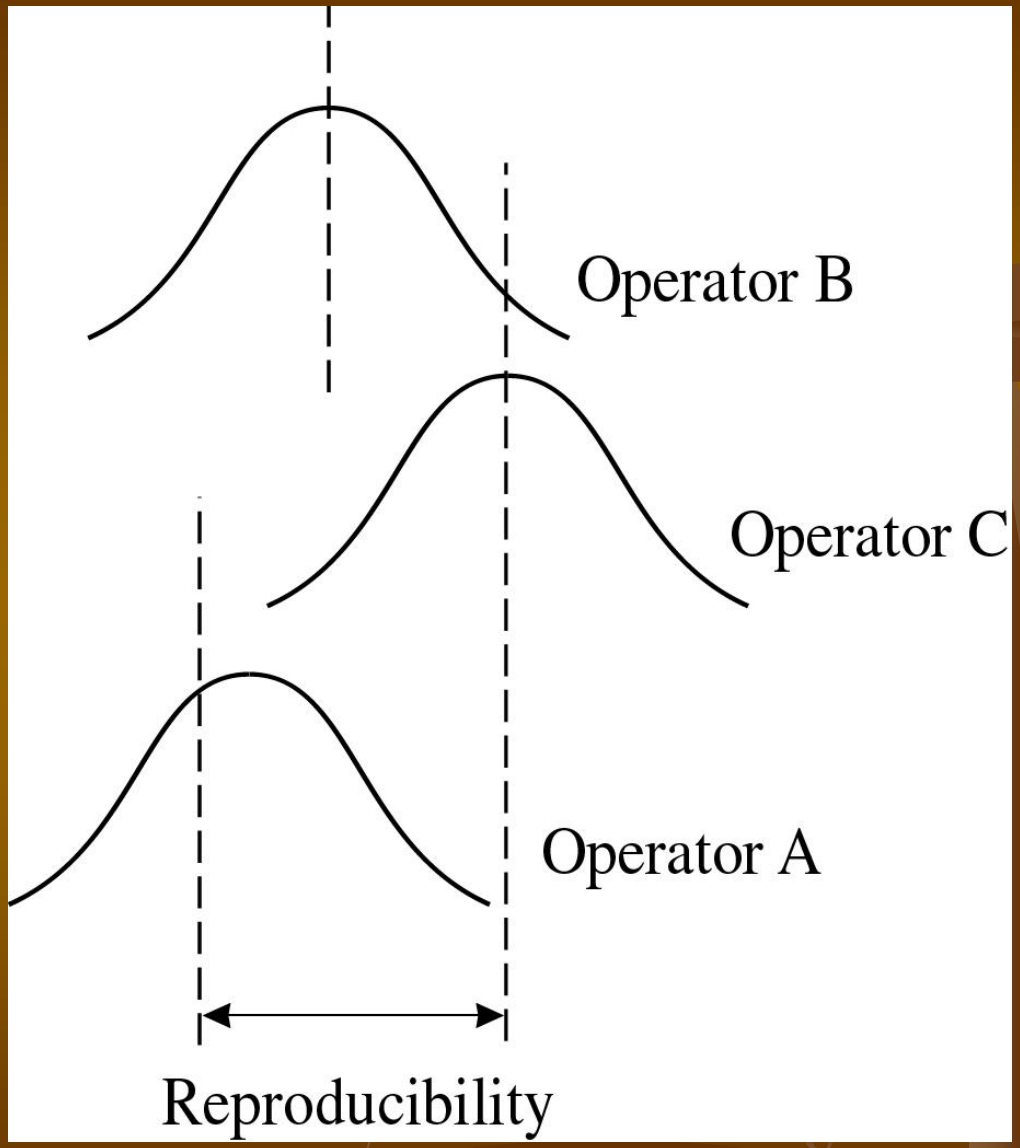


Fig. 15-2d

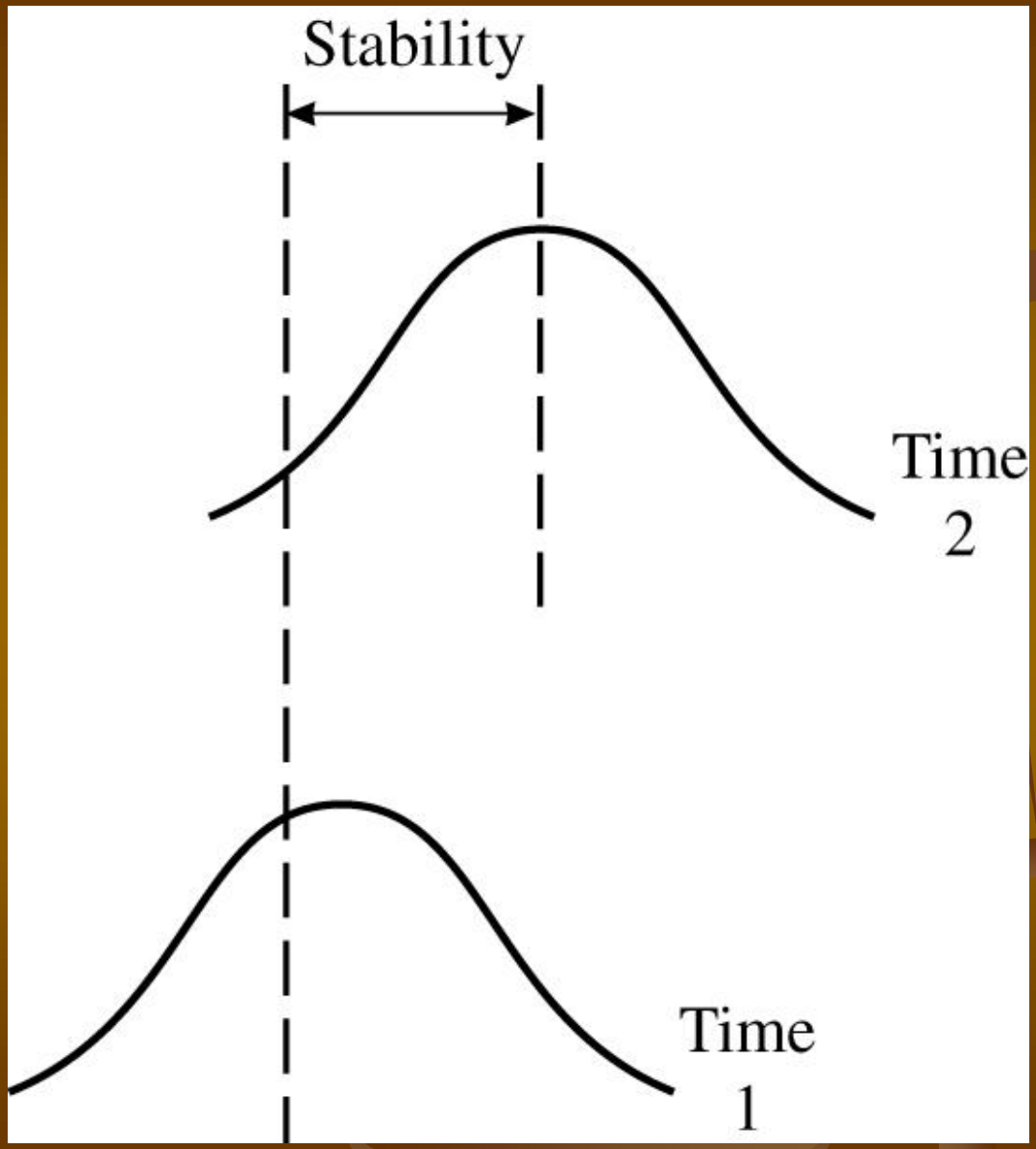


Fig. 15-2e

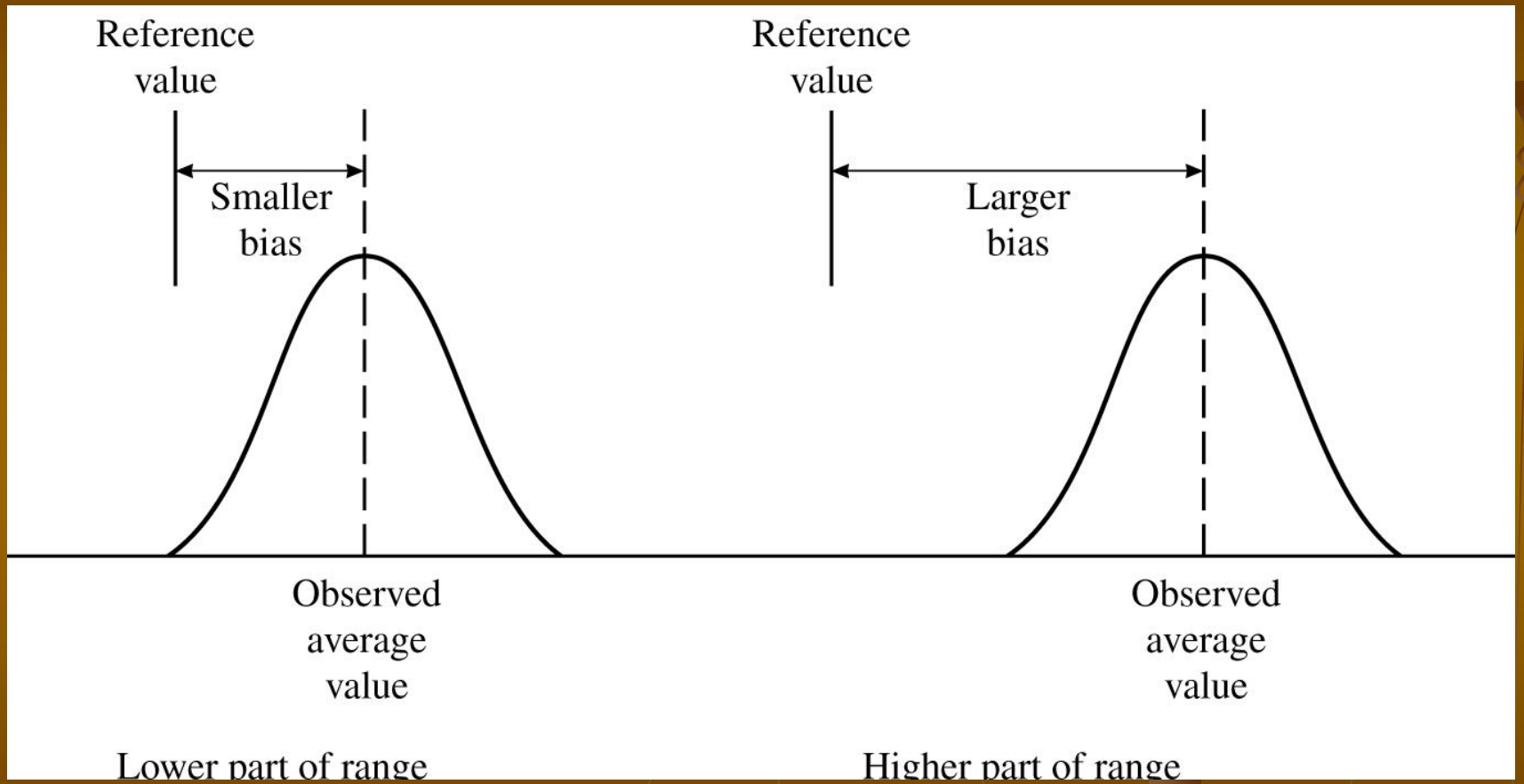
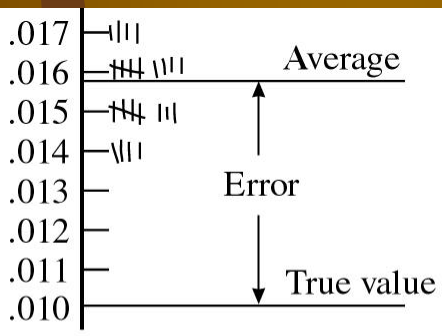
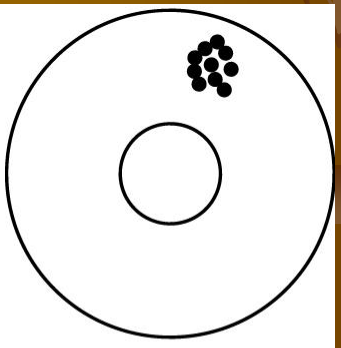
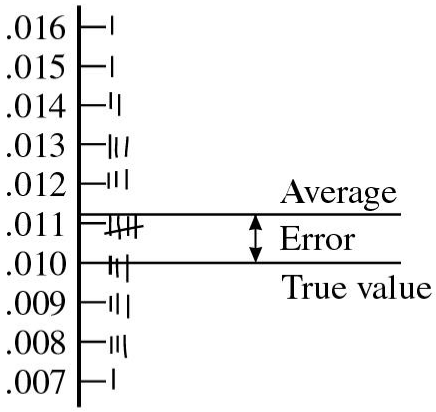

Reference value
Smaller bias
Observed average value
Lower part of range
Reference value
Larger bias
Observed average value
Higher part of range

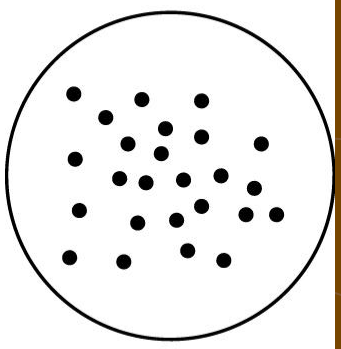
Fig. 15-3



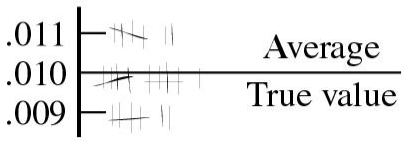


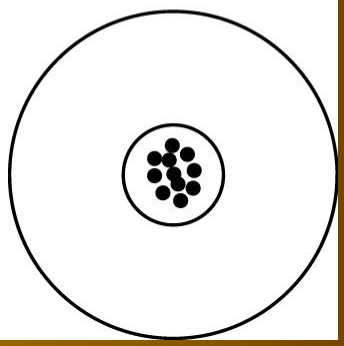
Precise, but biased





Unbiased, but not precise





Unbiased and precise

Validate Measurement System
Attribute Data Analysis – MSA 1

Sample #	Expert	Operator 1		Operator 2		Operator 3	
		Try 1	Try 2	Try 1	Try 2	Try 1	Try 2
1	Blister	Blister	Blister	Blister	Blister	Blister	Blister
2	Good	Light Ed.	Good	Good	Good	Good	Good
3	Drip	Drip	Drip	Dirt	Dirt	Drip	Drip
4	Dirt	Contam	Dirt	Dirt	Dirt	Dirt	Dirt
5	Contam	Contam	Contam	Good	Good	Over Run	Over Run
6	Blister	Blister	Blister	Blister	Blister	Dirt	Blister
7	Good	Good	Good	Good	Good	Good	Good
8	Dirt	Light Ed.	Contam	Good	Good	Dirt	Dirt
9	Good	Good	Drip	Dirt	Good	Drip	Drip
10	Good	Orange P.	Good	Good	Good	Good	Good
11	Dirt	Dirt	Good	Dirt	Dirt	Dirt	Dirt
12	Good	Contam	Light Ed.	Good	Good	Over Run	Over Run
13	Good	Light Ed.	Light Ed.	Good	Good	Light Ed.	Over Run
14	Contam	Contam	Contam	Good	Good	Good	Good
15	Drip	Drip	Light Ed.	Dirt	Good	Drip	Drip
16	Light Ed.	Light Ed.	Light Ed.	Good	Good	Good	Good
17	Dirt	Contam	Contam	Good	Dirt	Dirt	Dirt
18	Dirt	Contam	Contam	Dirt	Dirt	Dirt	Dirt
19	Blister	Blister	Good	Good	Blister	Blister	Blister
20	Good	Good	Good	Good	Good	Orange P.	Orange P.

Attribute Data Analysis-MSA 1 Results

Within Appraiser

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	20	11	55.0	(31.5, 76.9)
2	20	16	80.0	(56.3, 94.3)
3	20	18	90.0	(68.3, 98.8)

Matched: Appraiser agrees with him/herself across trials.

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	20	8	40.0	(19.1, 63.9)
2	20	11	55.0	(31.5, 76.9)
3	20	12	60.0	(36.1, 80.9)

Matched: Appraiser's assessment across trials agrees with standard.

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent (%)	95.0% CI
20	2	10.0	(1.2, 31.7)

Matched: All appraisers' assessments agree with each other.

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent (%)	95.0% CI
20	2	10.0	(1.2, 31.7)

Matched: All appraisers' assessments agree with standard

Note: 38% were called bad that were good. 22% were called good that were bad. This potentially could yield an improvement in the Defect rate by 16%

Attribute Data Analysis-MSA 2 Results

Within Appraiser

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	20	16	80.0	(56.3, 94.3)
2	20	19	95.0	(75.1, 99.9)
3	20	20	100.0	(86.1, 100.0)

Matched: Appraiser agrees with him/herself across trials.

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent (%)	95.0% CI
20	13	65.0	(40.8, 84.6)

Matched: All appraisers' assessments agree with standard.

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent (%)	95.0% CI
1	20	15	75.0	(50.9, 91.3)
2	20	19	95.0	(75.1, 99.9)
3	20	18	90.0	(68.3, 98.8)

Matched: Appraiser's assessment across trials agrees with standard.

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent (%)	95.0% CI
20	13	65.0	(40.8, 84.6)

Matched: All appraisers' assessments agree with each other.

Conclusion: MSA is greatly improved over first. Continue Q.C. training of inspectors to bring up agreement between all appraisers and standard.

Student Group Gage R&R Analysis Example

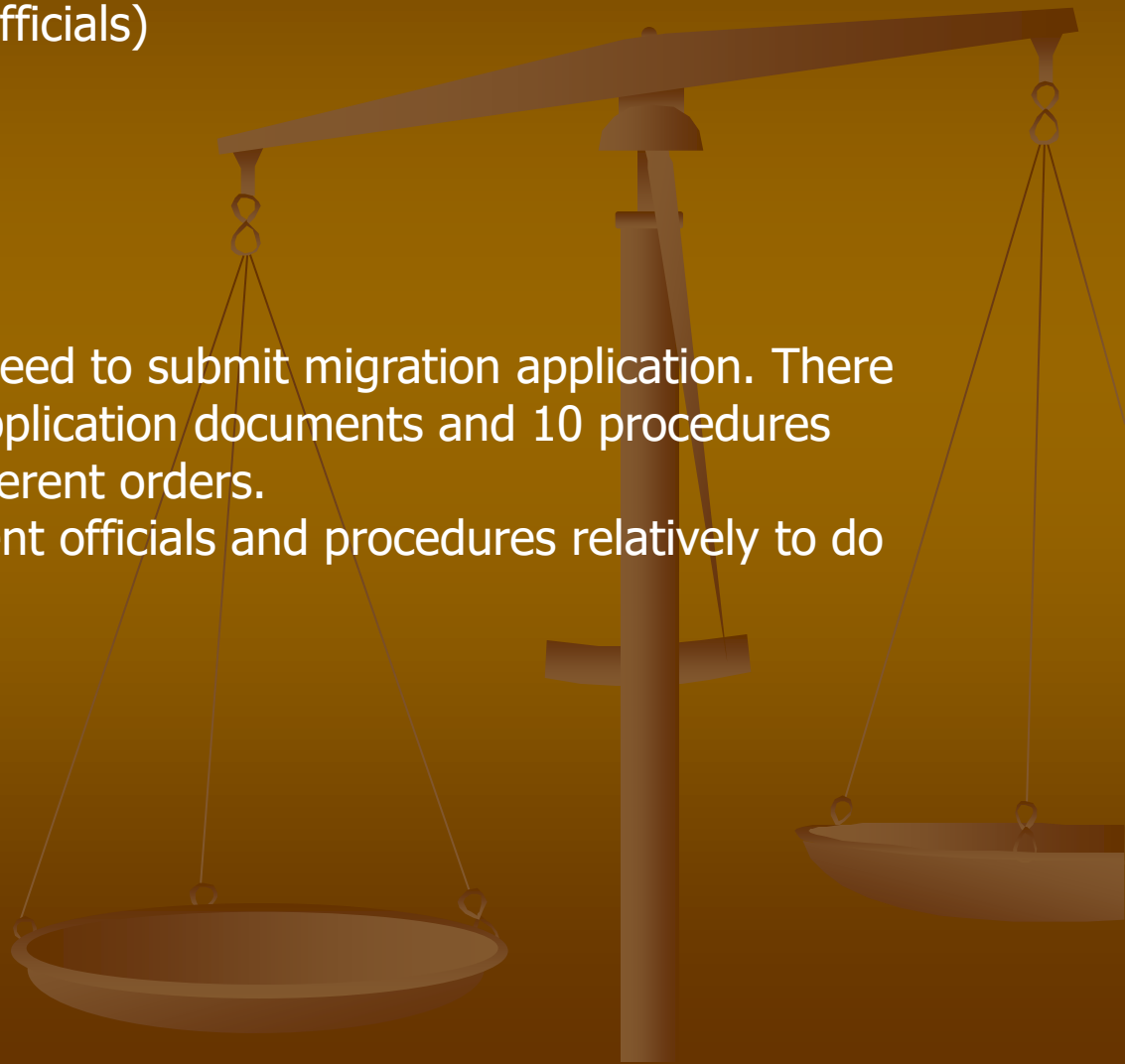
Group 1

Jorge
Vishnu
James
Alekhya
Hui Chen
Meng An

Gage R&R Considerations

- Number of Operators: 3 (Officials)
- Number of Procedures: 10
- Number of Trials: 2
- Number of Samples: 20

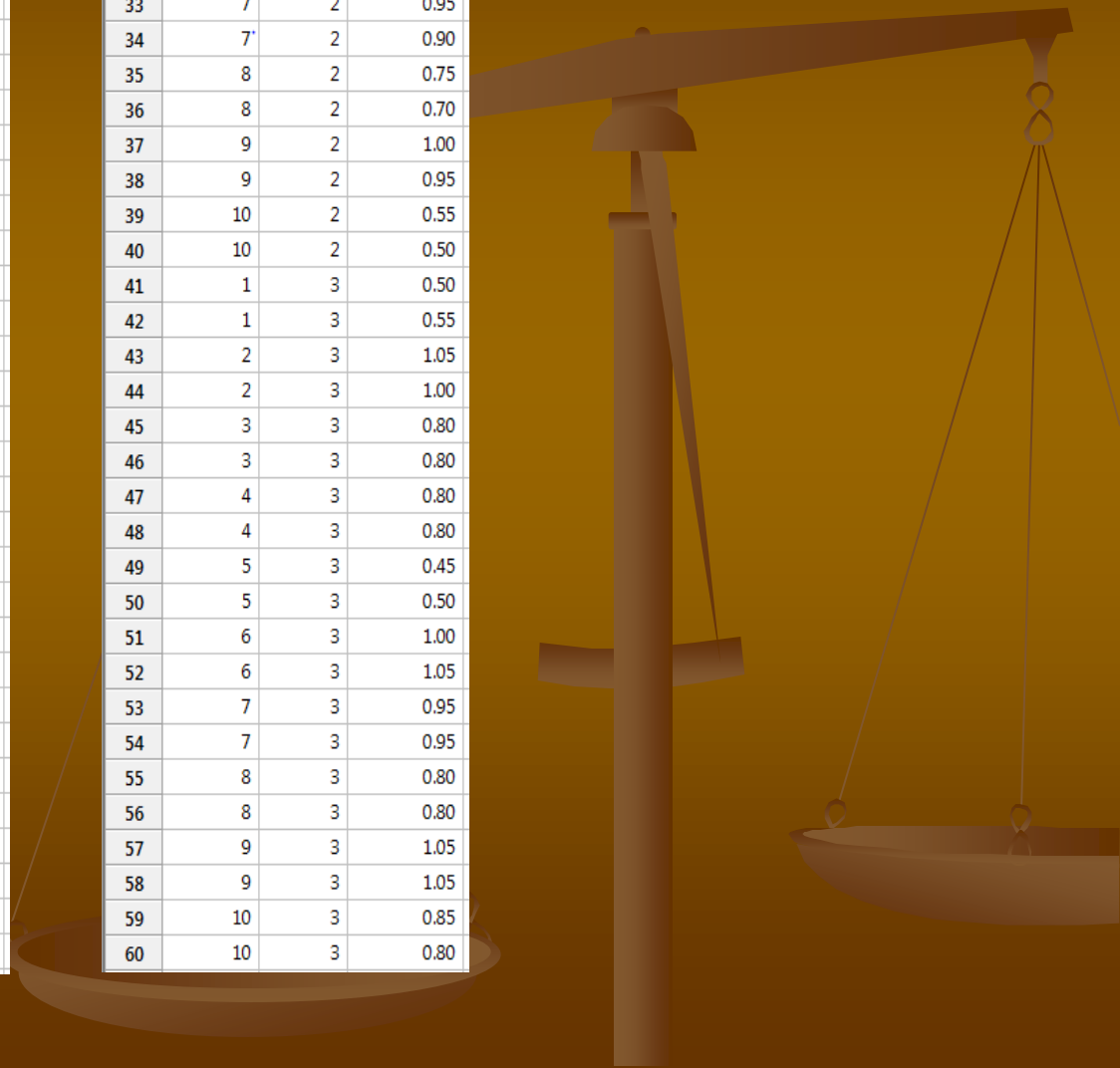
Refugees claiming for entry need to submit migration application. There are 3 officials handling the application documents and 10 procedures about filling in the files in different orders.
We took 2 samples for different officials and procedures relatively to do the Gage R&R analysis.



Appendix I.- Gage R&R Data

	Procedure	Official	Time (hours)
1	1	1	0.65
2	1	1	0.60
3	2	1	1.00
4	2	1	1.00
5	3	1	0.85
6	3	1	0.80
7	4	1	0.85
8	4	1	0.95
9	5	1	0.55
10	5	1	0.45
11	6	1	1.00
12	6	1	1.00
13	7	1	0.95
14	7	1	0.95
15	8	1	0.85
16	8	1	0.80
17	9	1	1.00
18	9	1	1.00
19	10	1	0.60
20	10	1	0.70
21	1	2	0.55
22	1	2	0.55
23	2	2	1.05
24	2	2	0.95
25	3	2	0.80
26	3	2	0.75
27	4	2	0.80
28	4	2	0.75
29	5	2	0.40
30	5	2	0.40

	Procedure	Official	Time (hours)
31	6	2	1.00
32	6	2	1.05
33	7	2	0.95
34	7	2	0.90
35	8	2	0.75
36	8	2	0.70
37	9	2	1.00
38	9	2	0.95
39	10	2	0.55
40	10	2	0.50
41	1	3	0.50
42	1	3	0.55
43	2	3	1.05
44	2	3	1.00
45	3	3	0.80
46	3	3	0.80
47	4	3	0.80
48	4	3	0.80
49	5	3	0.45
50	5	3	0.50
51	6	3	1.00
52	6	3	1.05
53	7	3	0.95
54	7	3	0.95
55	8	3	0.80
56	8	3	0.80
57	9	3	1.05
58	9	3	1.05
59	10	3	0.85
60	10	3	0.80



Results for; Worksheet 2

Gage R&R Study - XBar/R Method

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0020816	6.32
Repeatability	0.0011541	3.51
Reproducibility	0.0009275	2.82
Part-To-Part	0.0308455	93.68
Total Variation	0.0329271	100.00

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.045625	0.27375	25.14
Repeatability	0.033972	0.20383	18.72
Reproducibility	0.030455	0.18273	16.78
Part-To-Part	0.175629	1.05377	96.79
Total Variation	0.181458	1.08875	100.00

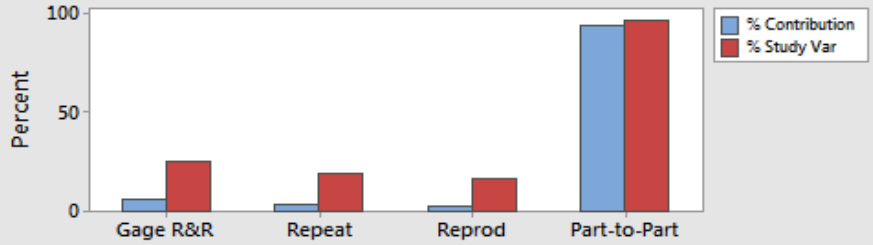
Number of Distinct Categories = 5

Gage R&R (Xbar/R) Report for Time (hours)

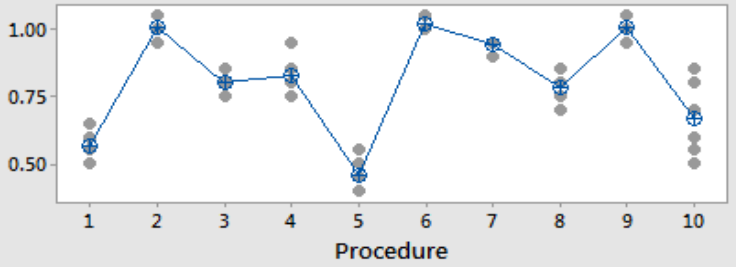
Gage name:
Date of study:

Reported by:
Tolerance:
Misc:

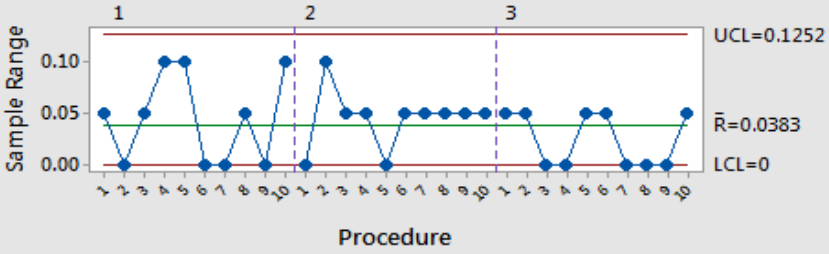
Components of Variation



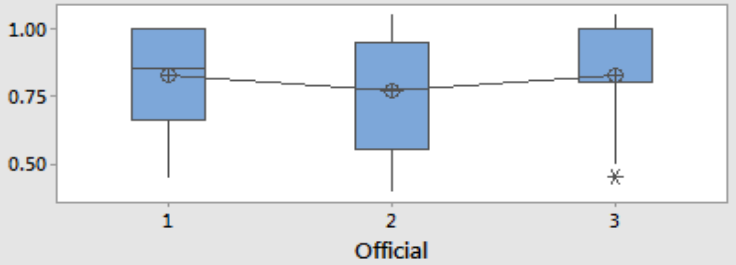
Time (hours) by Procedure



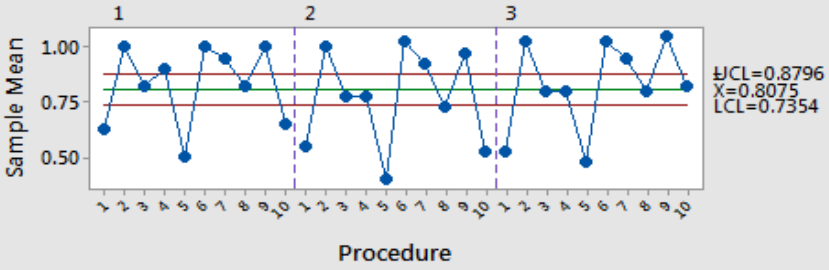
R Chart by Official



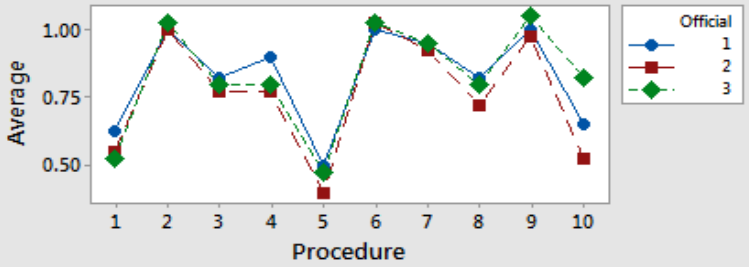
Time (hours) by Official



Xbar Chart by Official



Procedure * Official Interaction

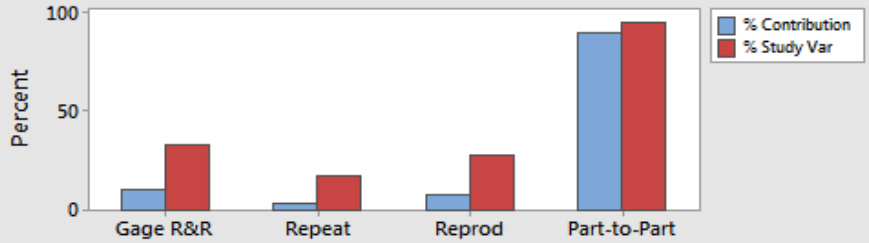


Gage R&R (ANOVA) Report for Time (hours)

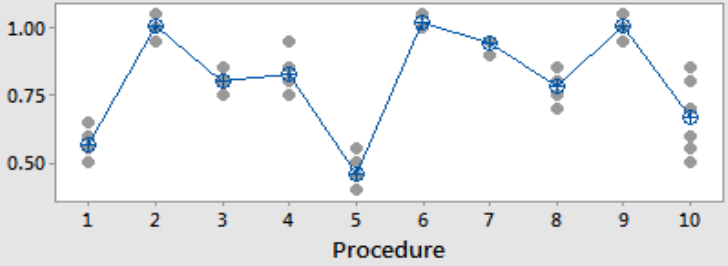
Gage name:
Date of study:

Reported by:
Tolerance:
Misc:

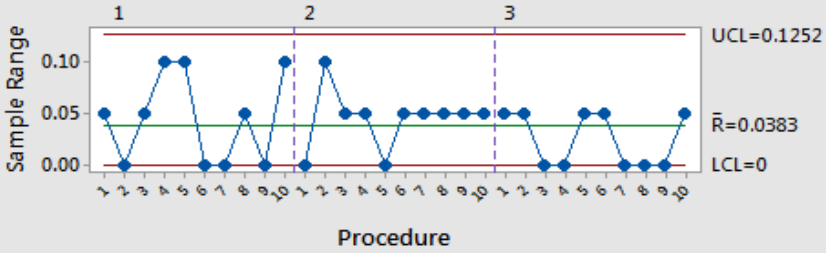
Components of Variation



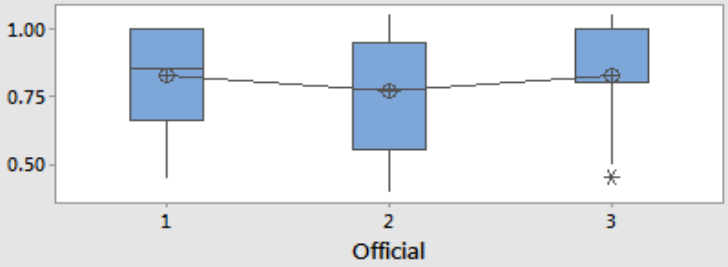
Time (hours) by Procedure



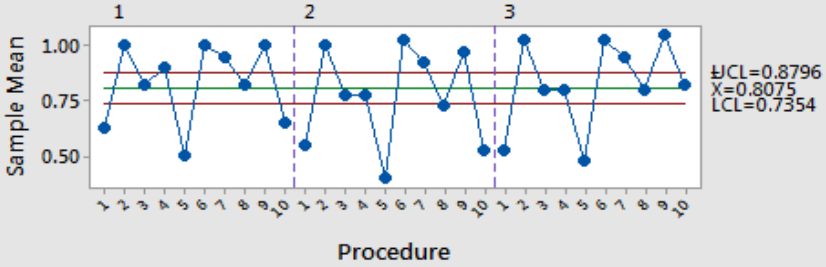
R Chart by Official



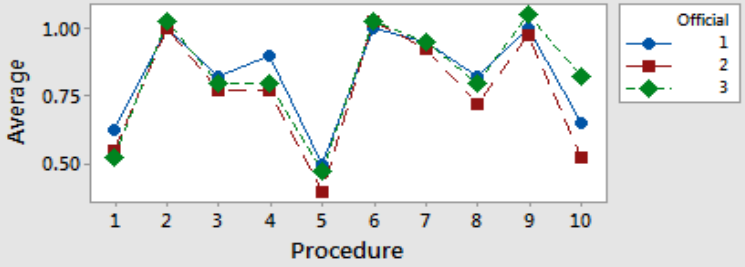
Time (hours) by Official



Xbar Chart by Official



Procedure * Official Interaction



Summary of Results and Analysis

- The following analysis was conducted following According to the Automobile Industry Action Group (AIAG) criteria:

If the Total Gage R&R contribution in the %Study Var column (% Tolerance, %Process) is:

- Less than 10% - the measurement system is acceptable.
- Between 10% and 30% - the measurement system is acceptable depending on the application, the cost of the measuring device, cost of repair, or other factors.
- Greater than 30% - the measurement system is unacceptable and should be improved.

The total Gage R&R was 32.66%. Therefore the measurement system is unacceptable. Considerations may be made to improve the process, to lower the total Gage R&R to 10% or less.

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

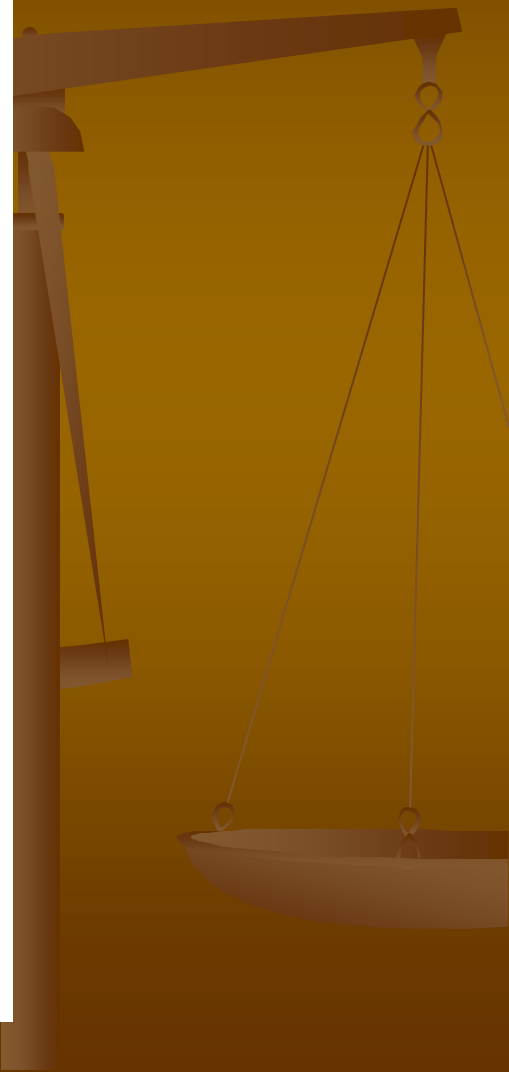
Source	DF	SS	MS	F	P
PERSON	9	10.1251	1.12501	15.6594	0.000
OPERATOR	2	1.1085	0.55425	7.7148	0.004
PERSON * OPERATOR	18	1.2932	0.07184	1.7416	0.046
Repeatability	90	3.7125	0.04125		
Total	119	16.2392			

Alpha to remove interaction term = 0.25

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.060958	40.99
Repeatability	0.041250	27.74
Reproducibility	0.019708	13.25
OPERATOR	0.012060	8.11
OPERATOR*PERSON	0.007648	5.14
Part-To-Part	0.087764	59.01
Total Variation	0.148722	100.00

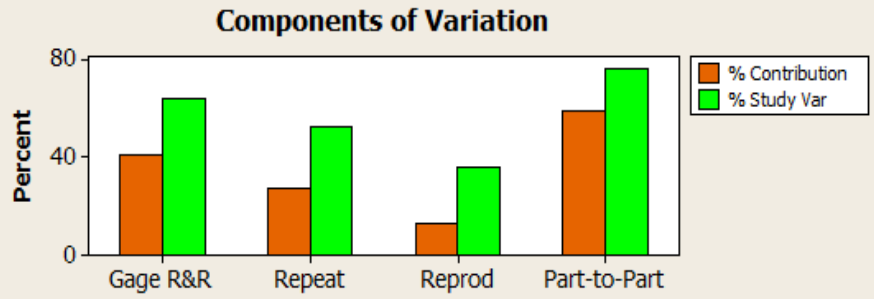
Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.246897	1.48138	64.02
Repeatability	0.203101	1.21861	52.67
Reproducibility	0.140386	0.84232	36.40
OPERATOR	0.109819	0.65891	28.48
OPERATOR*PERSON	0.087454	0.52472	22.68
Part-To-Part	0.296250	1.77750	76.82
Total Variation	0.385645	2.31387	100.00

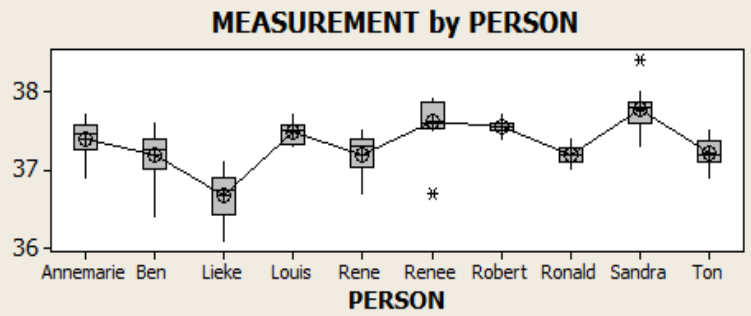


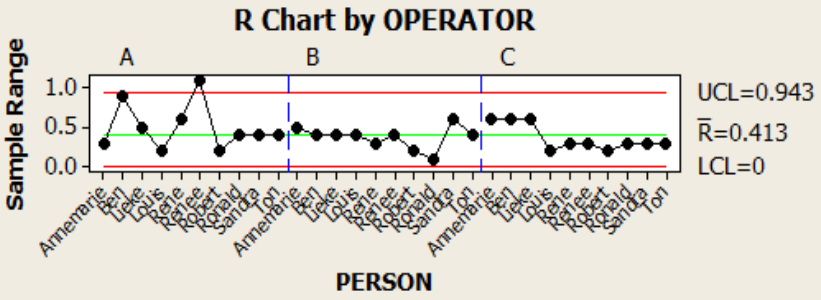
Gage R&R (ANOVA) for MEASUREMENT

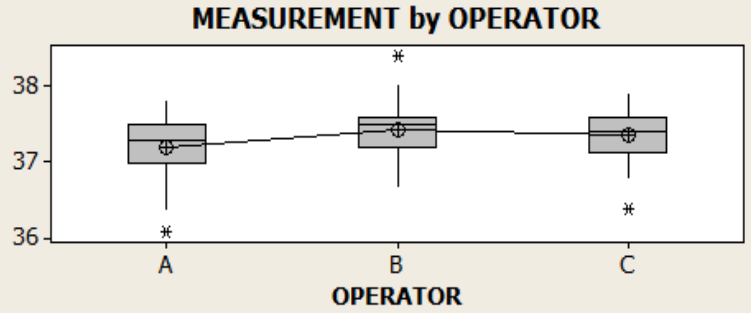
Reported by:
Tolerance:
Misc:

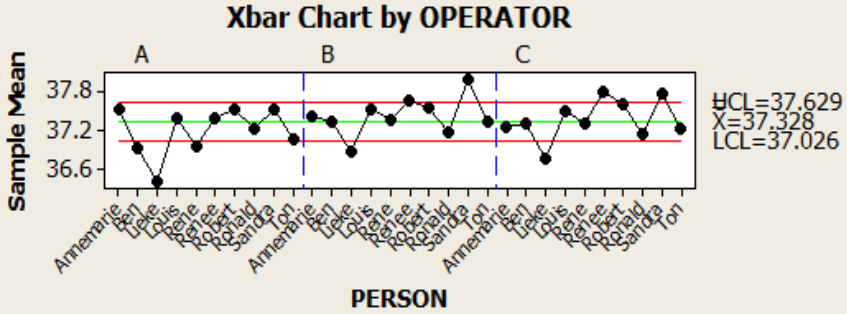
Gage name:
Date of study:

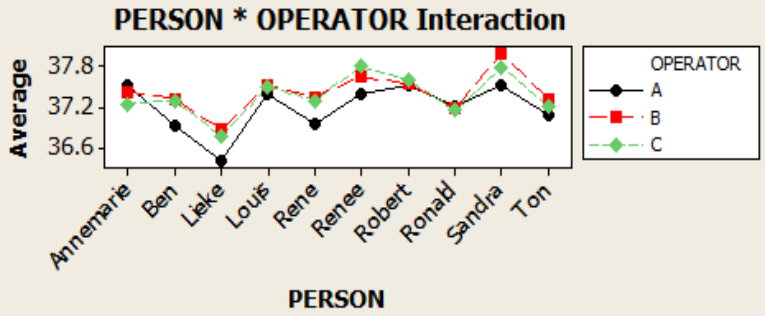












Thank-You

- Questions?