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The Unified Testing Equation

Understanding Everything in one Simple Expression

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Preface

- This presentation is UTE v1.0 (first edition)
- Updates will be made as more refined information avails itself
- General principle is basic and universal
- Scoring systems will be modified as understanding increases
- Objective is to remind test users of common sense approach
- Other General Rules
  - No accelerated test is 100% accurate
  - The only test that is 100% accurate is the results of actual use

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Test Motivations

- Generally a customer is concerned about
  - Price
  - Speed
  - Accuracy
- Old adage “Pick any Two”
- Low Price + Accurate = Outdoor Testing (not fast)
- Low Price + Speed = UVB Test (not accurate)
- Speed + Accuracy = Xenon Arc Test (not cheap)

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Overview

- Getting Good Results are directly related to
  - Expense: Better tests cost more
    - More services
    - More accuracy
  - Rate: Faster tests mean quicker decisions
    - Earlier to market
- Getting Good Results are inversely related to
  - How complicated the test is to run
  - Reciprocity of ultra-accelerated tests
    - Fast tests that have poor simulation

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Quality of Test (Q_t)

- Q_t is the unitless value "Quality of the test result"
- The higher the value the better the test
- Overall result influenced by many factors
- aka "Customer Happiness Index"
- Common sense approach to deciding best test
  - What services to request
  - Which equipment to use
  - What cycle to run

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The Unified Equation

$$Q_t = [(V - C)x(R\ r^n)] - M$$

Q_t = Quality of the test result

V = Value of the Test, which is the Features per Price (V = F/P)

C = Degree of Complexity (Difficulty) of the Test

R = The Rate of Acceleration of the Test

r = Reciprocity

n = Power Index for reciprocity

M = Mistakes (Human Error)

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Value of Test

$$Q \sim V$$

- Quality is directly related to value
- Value is Features per Dollar (V = F/P)
- Generally, the more you pay for a test then the better the results
- Higher price only good if benefit is more features
- Additional services during the test are beneficial features
- A really cheap test might not be trusted
- A more expensive test usually uses better equipment, more highly trained staff

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Scoring System (F/P)

Features

- 1 each for all that apply, e.g.,
- Visual Evaluations
- Instrumental Measurements
- Interim Reports
- Statistical Analysis
- Realistic Conditions
- Accurate Spectra

Price

- 1 if Price < $1,000
- 2 if Price is $2,000 - $5,000
- 3 if Price is $5,000 - $10,000
- 4 if Price is $10,000 to $25,000
- 6 if Price is $25,000 to $50,000
- 8 if Price is $50,000 to $100,000
- 10 if Price is > $100,000

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Lessons

- Don’t cut costs where it is important
- Spend extra to test more replicates
- Don’t skimp on evaluations
  - But only evaluate as necessary
  - Less expensive alternatives during test, more expensive at end
- Test as many as minimums will permit
- Make sure you get the specimens back at the end of the test

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Complexity (Degree of Difficulty)

$$Q \sim 1/C$$

- Simple tests are the best
- Complexity causes errors
- Examples
  - Too many steps in a cycle
  - Test Method requires excessive precision
  - Test Equipment with too many buttons
  - Unrealistic ramp rates

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Scoring System for C

Add 1 for each of the following that apply

- More than 4 steps in the cycle
- Requires more than one piece of apparatus
- Uses more than location
- Requires manual input, not an automatic cycle
- Uses high maintenance equipment
- Specifies a non-standard test
- Uses slow “controlled” ramp times
- Remote location for outdoor testing

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Lessons

- More complex tests can cause errors
- Complex tests usually require complex equipment
- More complex tests do not necessarily match real world
- False sense that complexity equals accuracy

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Reciprocity

$$Q \sim r$$

- Reciprocity directly affects the relationship of the rate of the test
- Reciprocity is 1.0 for perfect reciprocity to 0.0 for no reciprocity
- If true reciprocity (r = 1.0) is in effect, then the rate of the test has no effect on the quality of the results
- There are still increased benefits to the test if the rate increases and the r only decreases slightly
- Reciprocity is not uniform for all exposure conditions
- If reciprocity decreases greatly, poor correlation is inevitable

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- Reciprocity is a gauge of how well the results remain the same as the severity of the test increases.
- Basically the index is derived from the same statistical comparison at different rates, for example
  - Rank Correlation
    - Example R = 0.90 at zero acceleration but 0.70 at 2x acceleration
  - T-test comparison of means
    - Example t = 0.95 (95%) at zero acceleration but 0.925 (92.5%) at 2x acceleration
- If actual reciprocity cannot be calculated use the following scale

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Scoring System for reciprocity r

- Use the following power index for each that apply
- 1 for no changes, this is the base level
- Temperature
  - 0.5 points > 10 °C different from service use
  - 1 point > 20 °C different from service use
- Irradiance
  - 0.5 points > 10% different from service use
  - 1 point > 25% different from service use
- Total Wet Time
  - 0.5 points > 10% different from service use
  - 1 point > 25% different from service use
- Max index is 4 if all the above are true

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Lessons

- Reciprocity is when the results still match even after acceleration
- No effect on the results as acceleration is added
- Example of true reciprocity
  - Double the irradiance, duration is halved, results are the same
  - Quadruple the irradiance, duration is quartered, results are the same
- Example of failed reciprocity
  - Double the irradiance, duration is halved, results are different
  - Double the irradiance, duration is the same, results are different
  - Double the irradiance, duration is halved, ranking is the same, but different failure modes recorded

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Rate

$$Q_t \sim 1/R$$

- Quality is proportional to the degree of acceleration
- Generally speaking, the faster the test, the less accurate
- Acceleration Rate is not usually linear
- A faster rate is required for an “accelerated” test
- Industry always pushing for ever-faster tests

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Scoring System for Rate R

Estimate the acceleration factor for the test versus the service use

- Examples for outdoor tests
  - Testing in Florida is generally 2 to 4 times faster that other temperate areas
  - Testing in Arizona can be up to 5 times faster
  - Black Boxes are twice as fast as a direct rack
- Examples for accelerated tests
  - Solar concentrators are 5 times faster than Florida
  - UVA tests can be up to 1.75 times Florida sunlight
  - UVB tests might be 3 times Florida UV energy

Total up every acceleration factor that applies

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Lessons

- Some acceleration is good
- Ultra acceleration must always be used cautiously
- There are thresholds of acceleration
- Must know the limits of reciprocity

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Mistakes

$$Q_t \sim 1/M$$

- No matter how good everything else might be
  - Human error can screw it all up
  - One mistake ruins the whole test
- Error examples
  - Break the specimens
  - Interruptions – too many or too long
- A faulty tester or test set up ruins all
- However, the test can be repeated if error is known

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Scoring System for Mistakes M

- Deduct 25% for the following errors
  - Some of the evaluations were performed incorrectly
- Deduct 50% for the following errors
  - Specimens were damaged or compromised
- Deduct 100% for the following errors
  - The wrong cycle was used in the accelerated test
  - Specimens were prepared incorrectly
  - The wrong goal was set for the tests
  - The method did not answer the original goal

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List of Fatal Mistakes (M=100%)

- Choosing the wholly wrong test method
  - e.g. running an outdoor daylight source for interior material
  - Picking the wrong spray cycle to simulate Florida
  - Specifying the incorrect temperatures
- Incorrect sampling of test specimens
- Incorrect test specimen preparation
- Not evaluating for all know failures
- Ending the test too soon
- Not using the correct controls or reference materials

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Application of the UTE

- Keep tests simple and realistic
- Use test cycles that simulate the end use
- Stay away from overly complex cycles
- Don’t go for the ultra-accelerated test
- Don’t settle for cheap tests or equipment
- Get more services, but only when essential
- Accelerated tests are more useful than slower tests
- Florida and Arizona are excellent options
- Use proven and well-known test methods

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What does the UTE teach us?

$$Q_t = \left[\left(V - C\right) x \left(R x r^{n}\right)\right] - M$$

- Positives are Value, and Acceleration Rate
- Negatives are Complexity and Reciprocity
- Mistakes are career-killers
- Only pay for what you really need
- Do not use overly complicated tests
- Verify your accelerated data with non accelerated references
- Eliminate mistakes