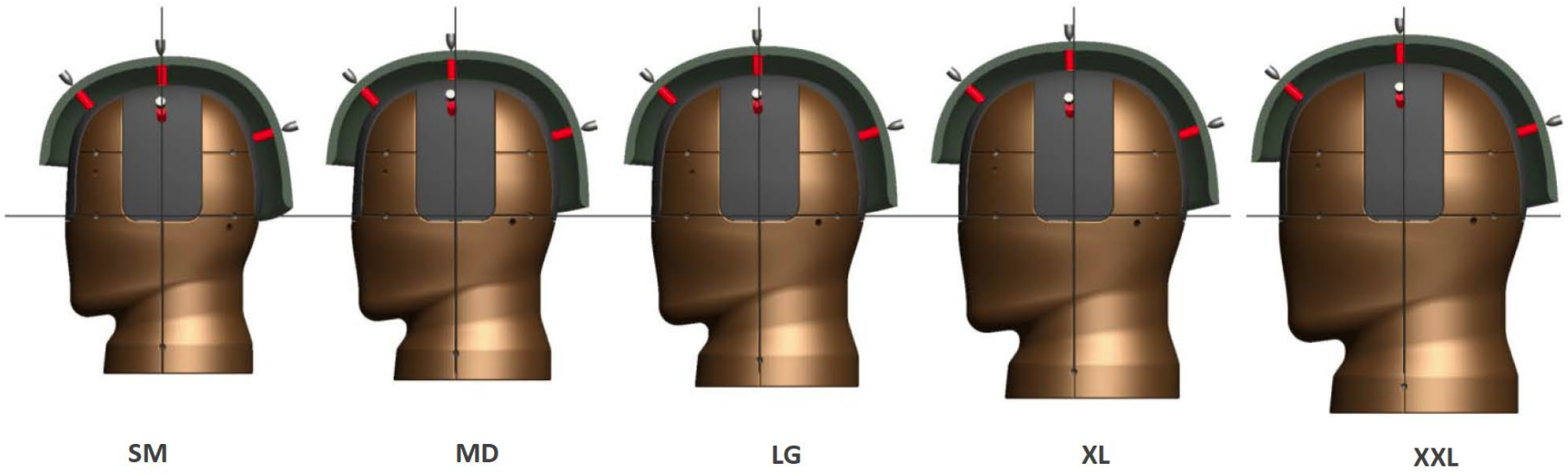
A Review of Combat Helmet Acceptance Testing

a. Penetration-Resistance

1. Legacy Acceptance Plan: 4 helmets
   (1 size x 4 envs.) x 5 shots:
   OK if 0/20 penetrations

2. OT&E Plan (Sep. 2011): 48 helmets
   (4 sizes x 4 envs. x 3 reps) x 5 shots:
   OK if </= 17/240 penetrations

Test Fixtures



- Five patterned 9mm shots: front, crown, back, left, right
- data: penetrations; back-face deformation (dent in clay)

Reaction: Rep. Louise Slaughter (June 2012)

- I think 17/240 test plan poses "unacceptably high risk" to soldiers
- Director, OT&E (July 2012): Not to worry because: STATISTICS.
- OT&E to Nat'l. Acad. Sci. Comm.: Pls. analyze, evaluate, explain, …

Q & A

- **Why 240?**
  - Greater coverage of operational space; more precision (esp. w.r.t. BFD = Back-Face Deformation = max depth of head-form indentation)
- **Why 17?**
  - The "90/90" criterion
  - Under binomial assumptions, with worst-case acceptable result, 17/240, lower 90% conf. limit on *non-pen.* probability is .90

Comment

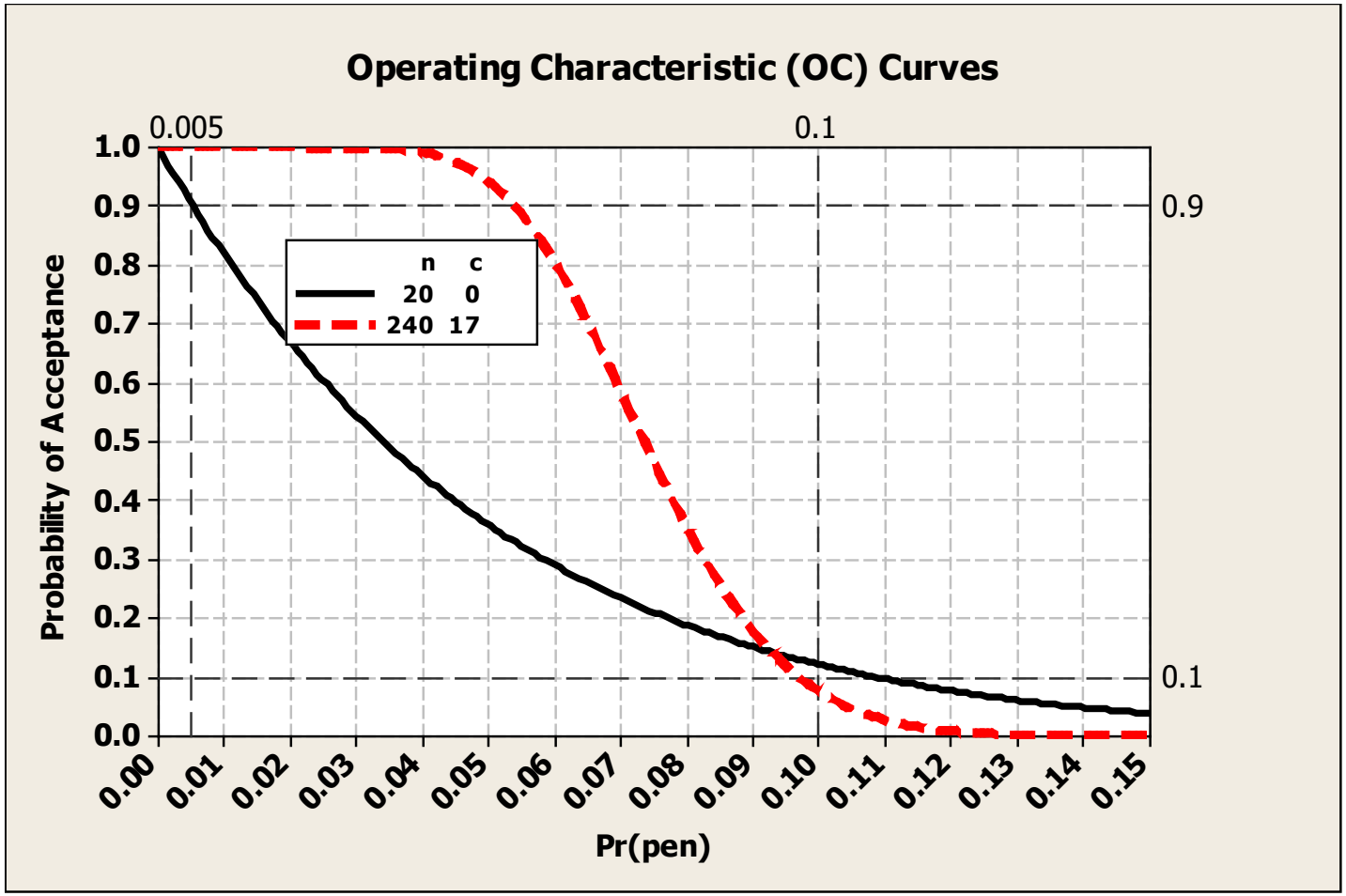
- Worst-acceptable-case lower 90% conf. limit on non-pen. probability is awkward way to characterize acceptance plan.

- More direct way: Plan has a 90% probability of rejecting helmets with an underlying 10% penetration probability

Why 90/90?

- 0/20 plan has approximately this property
- Previous Natl. Acad. Sci. Body-armor report suggested some plans with this property
- *But, no empirical or scientific reason to set pen-prob of .10 as the "standard" or limit on acceptable pen-prob.*

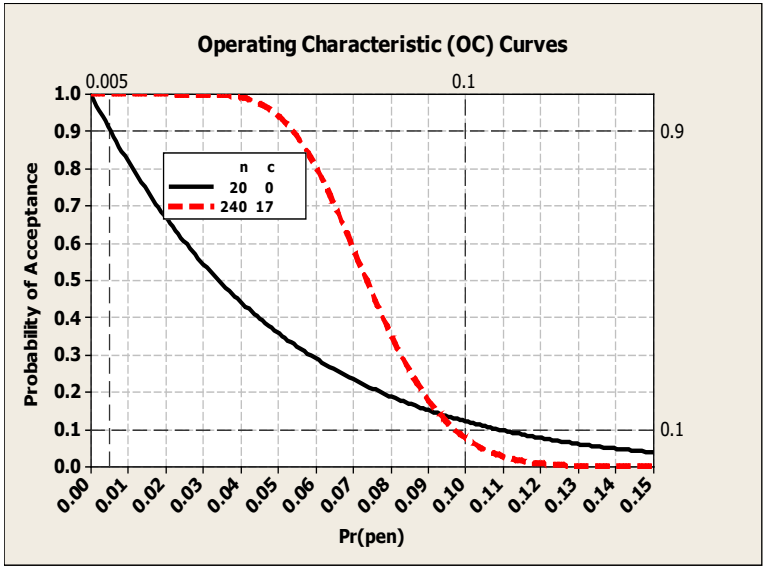
O.C. Curves:
0/20 and 17/240 plans



Manufacturer's Incentive

- To have 90% chance of passing acceptance test

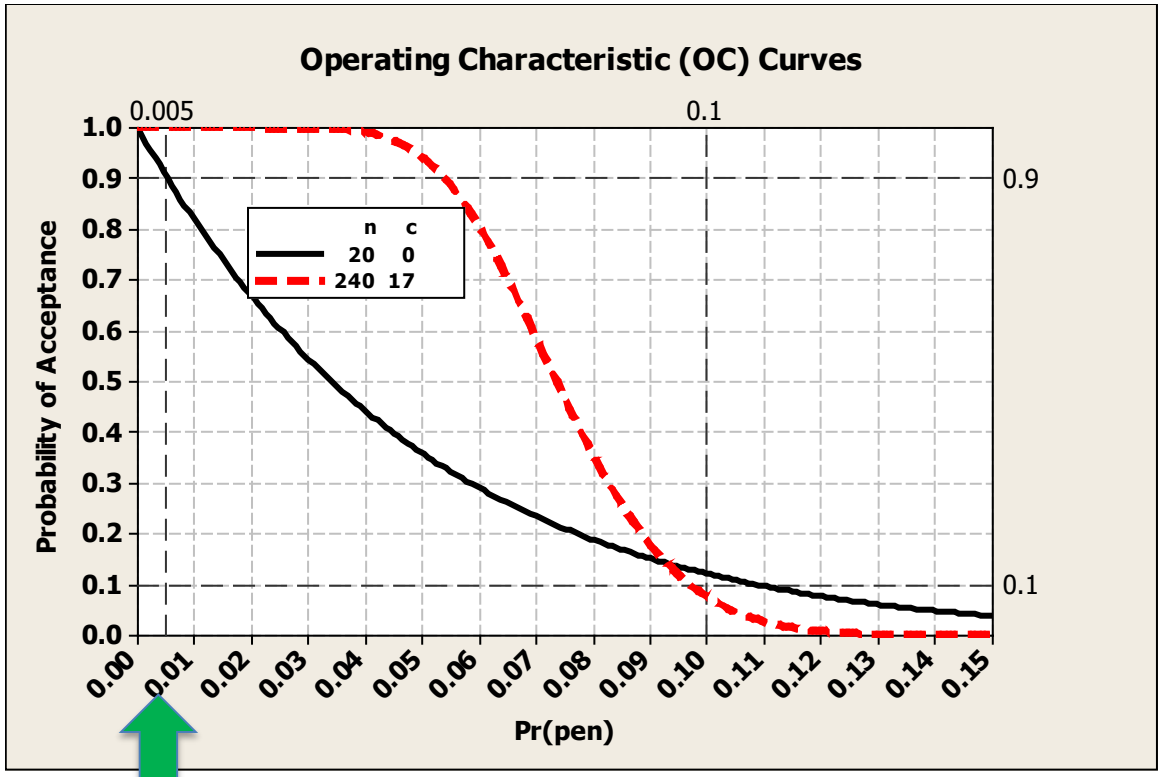
Plan	pen-prob
• 0/20	.005
• 17/240	.055



We Need Data:
How penetrable are current helmets?

- Short Summary
  - ~12,000 shots; 7 penetrations
  - (no helmets failed 17/240 test)
  - estimated pen-prob < .001
  - worst subset, upper 90% C.L. .004
- This tells us where to look at the O.C. curve

Data Message: Manufacturers are in sync with incentive of 0/20 plan



Current Data

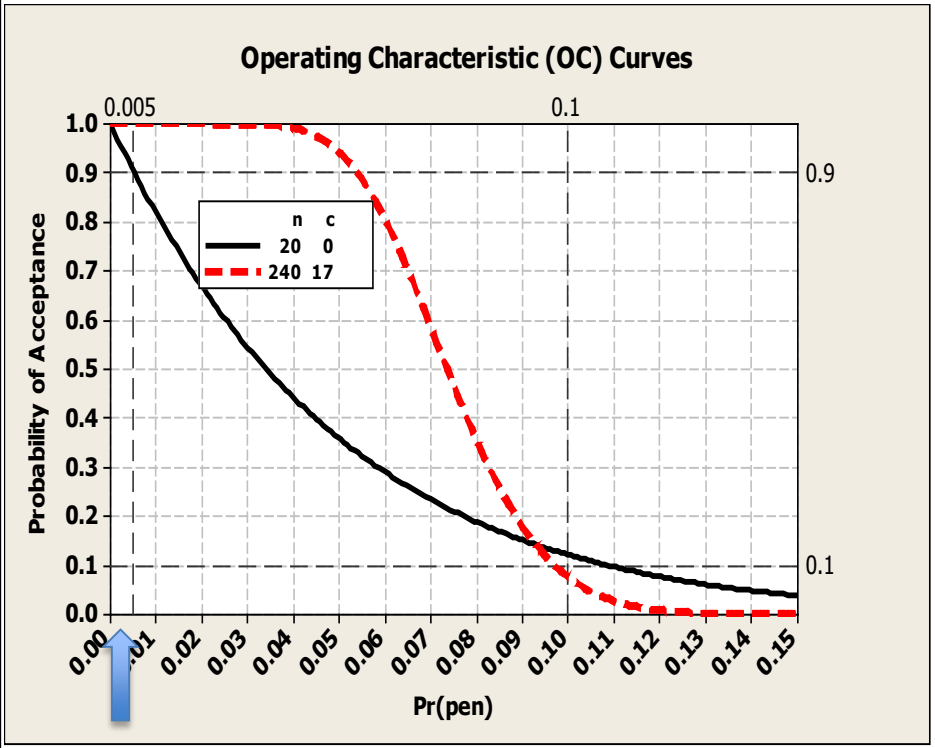
Mfgs. about 100x better than the 10% pen-prob "standard"

Committee Position

- There is no scientific or empirical basis for setting pen-prob = .10 as a 'standard'; current helmets much better
- *Acceptance test should be designed to provide adequate assurance that new helmets are not more penetrable than existing helmets*
- 17/240 does not meet that criterion. Helmet 10x current helmet pen-prob would be very likely to be accepted.

In Essence …

New plans should be designed so that their O.C. curves resemble the left end of the 0/20 plan's O.C. curve, not the right end.



data

Comment

- DOT&E, in ltr to Rep. Slaughter, recognized reduced manufacturer's risk/incentive, but said that would be OK for future lighter-weight helmets
- Committee charter and DoD protocol were for all helmets
- Trade-off bet. wt. and pen-prob needs to be addressed directly.
  - e.g., 10x higher pen-prob vs. 10% lighter?

Towards Determining Limit for Penetration Probability

- Simple model: Given a helmet shot:

  Pr(death) =

  Pr(death:pen) x Pr(pen) +

  Pr(death:$\overline{\text{pen}}$) x [1-Pr(pen)]

  If the Pr(.:.)s are known (well-estimated), DoD could set a goal for Pr(death), solve for Pr(pen) req't.

b. Back Face Deformation

- Legacy Plan
  - compare BFD to specified limits, defined by shot location
  - Score: Fail if BFD > Spec Limit
  - Helmet accepted if 0/20

DOT&E Plan

- For designated subsets of BFD data, calculate upper 90/90 Normal distribution statistical tolerance limit.

- OK if 90/90 UTL < Spec, all subsets
  - This is a 90/10 plan for variables

Motivation

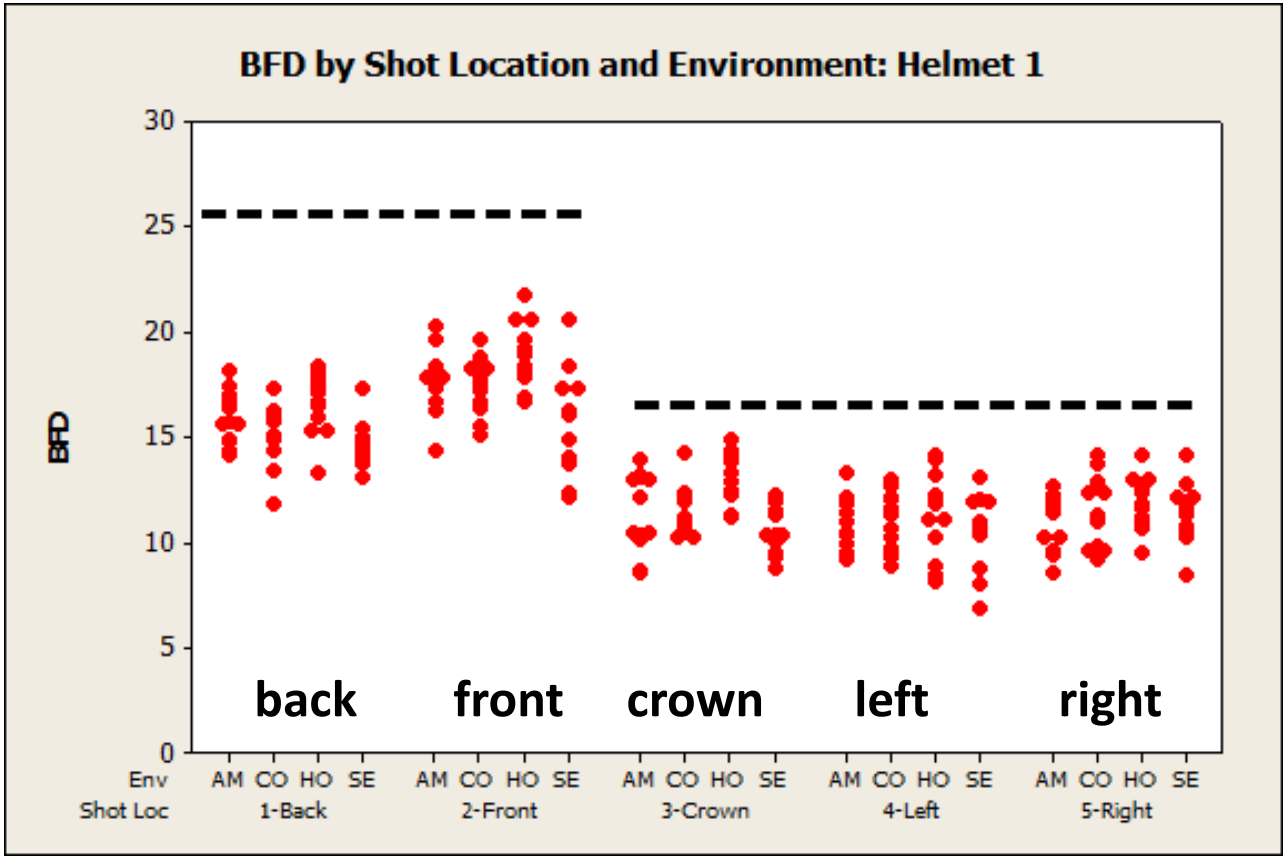
- Variables data more informative than attributes data:
  - steeper O.C. curves,
  - tighter confidence intervals,
  - etc.
- Stat'l analyses can 'characterize' BFD distributions as function of env., shot location, helmet size

Issues

- How to split/pool data?
- Normality assumption?
- Complexity?
- Justification of BFD spec limits?

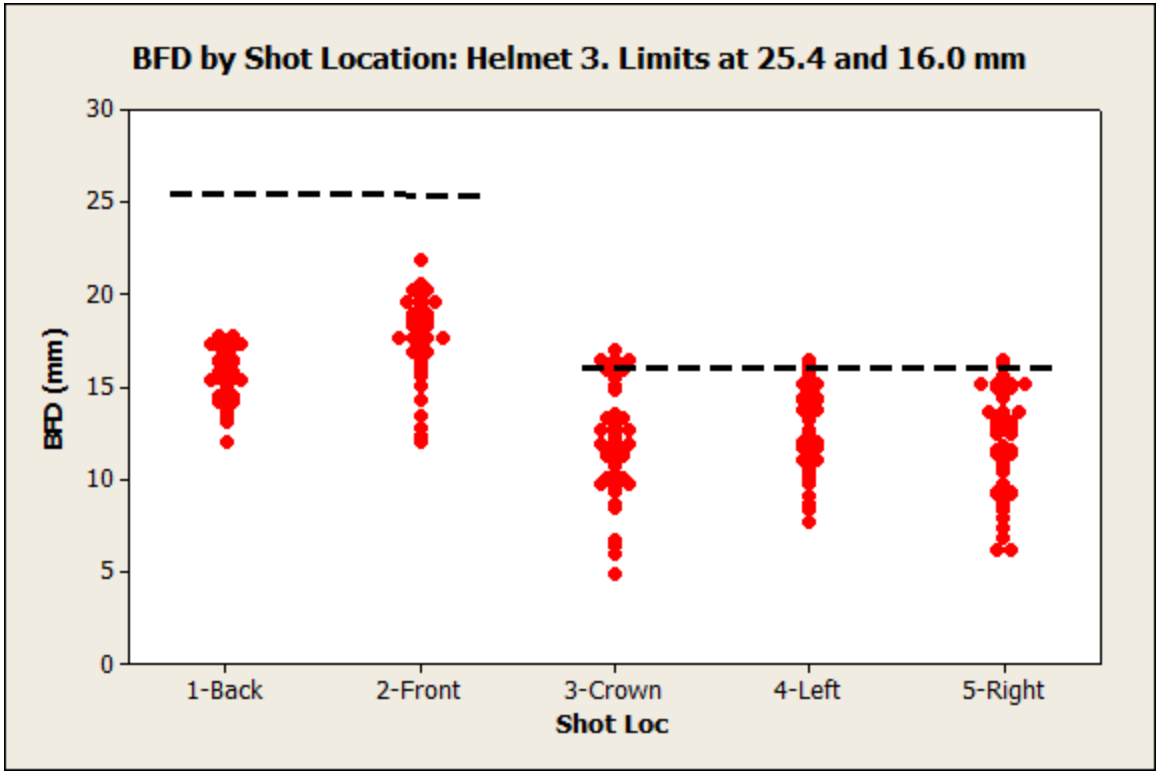
Let's look at some data

H1: BFD by Shot Loc. and Env. vs. Spec Limits of 25.4 and 16.0 mm



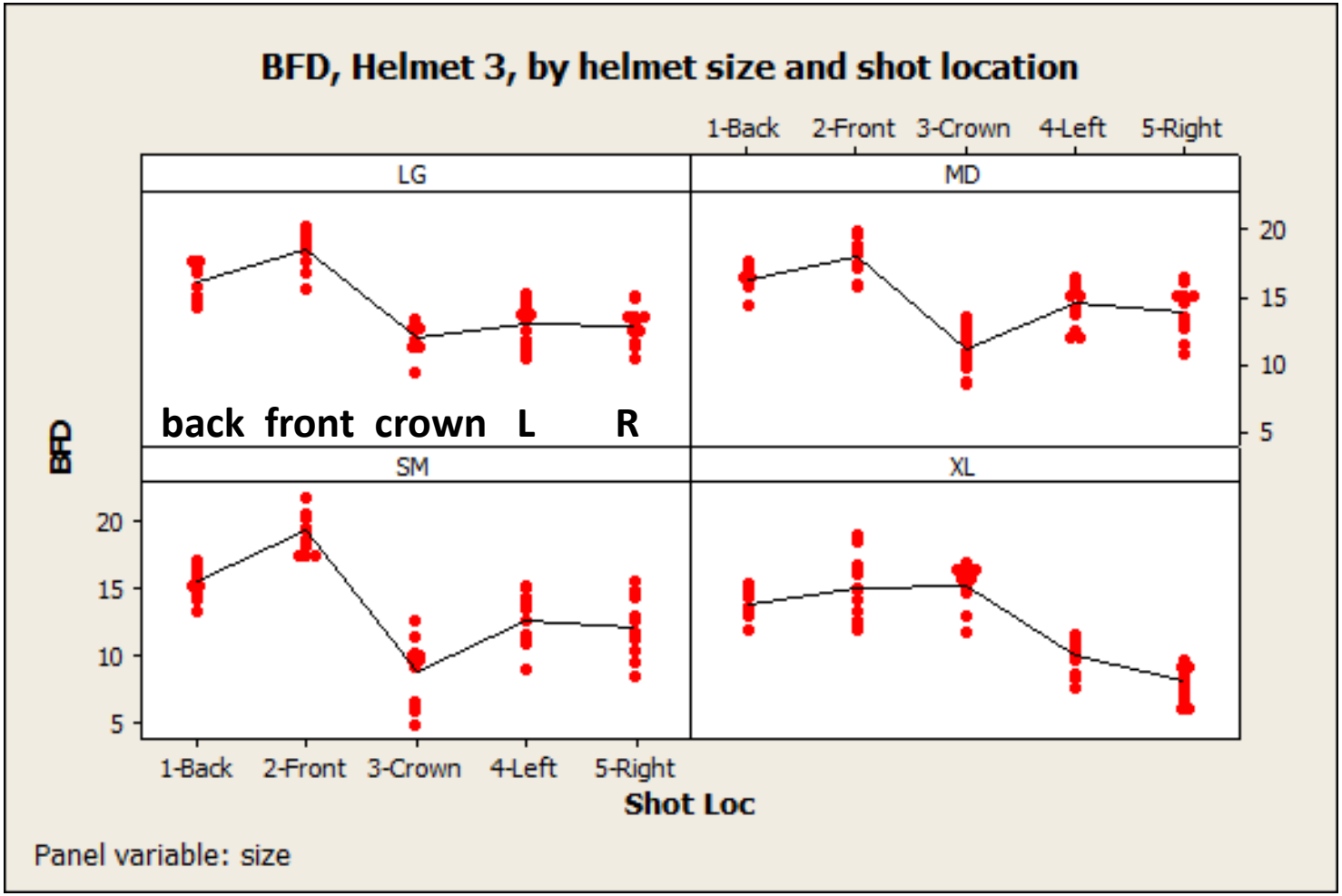
Note. A 20 mm dent in your head is OK, front or back, but not left, right, or crown.

H3: BFD by Shot Loc. vs. Spec Limits



a few exceedances, << 10%

H3: BFD by Shot Loc. and Helmet Size



Complexity - 1

- Tolerance limits are hard to explain – two probabilities to keep straight
- The TL criterion is equivalent to a margin criterion

  Margin = (USL – ybar)/stdev > K*
- Can design acceptance plans (n, K*) to meet two O.C. specs

Comment

- Calculating upper T/Ls after obtaining the data would be appropriate, but it's unnecessary and awkward to state test plan in terms of upper T/L
- It's a margin test – how many sigmas of margin do we need?

Complexity - 2

- Pre-analysis analyses w.r.t. pooling can greatly complicate O.C. curves

- Compound Decision: Mfg. passes if UTL criterion is met for all data subsets?

Cultural Considerations

- Statisticians salivate at large amounts of multi-factor data
- Others gag
  - Archie Bunker: *"Don't give me no stastistics, Meathead! I want facts."*
- NAS Report: Go back to binomial scoring – with meaningful spec limits

Spec Limits

- Legacy Spec Limits by shot location have no empirical or scientific basis
  - They reflect manufacturers' capability, not injury risk
- Suggestion: Use data to develop Spec Limits aimed at assuring new helmets are as BFD-resistant as current helmets

Results of NAS Report
(available from National Academies Press)

- More banter between DoD and Rep. Slaughter

- New Acceptance Test Plans?
  - tbd ?
  - Army previously changed 17/240 plan to two-stage plan:
    (i) 0/22, then (ii) 17/218
  - more stringent than 0/20