Combining Professional Judgment and Exposure Data - Bayesian Decision Analysis

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Bayesian Decision Analysis (BDA)

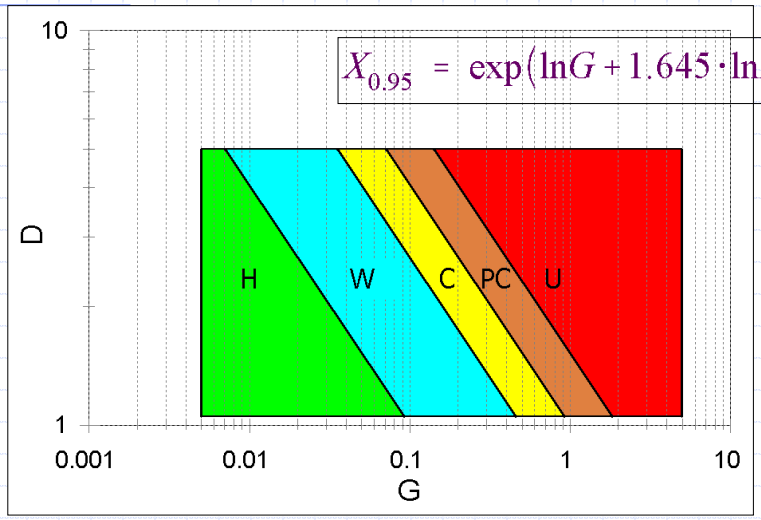
- An adjunct or alternative to the calculation and interpretation of traditional statistics.
- The goal of BDA is to estimate the probability that the *true* exposure profile falls into a particular category, or *Rating Zone.*

Rating Zones* for TWA OELs

AIHA Rating	EAS Inc. Rating	Statistical Definition (L=limit)
1	Highly-controlled – HC	$X_{0.95} \leq 10\%$ L
2	Well-controlled – WC	10% L $< X_{0.95} \leq 50\%$ L
3	Controlled – C	50% L $< X_{0.95} \leq 100\%$ L
4	Poorly-controlled – PC	100% L $< X_{0.95} \leq 200\%$ L
	Uncontrolled – UC	$X_{0.95} > 200\%$ L

*Adapted from Mulhausen and Damiano (AIHA, 1998)

Rating Zones for TLV = 1 ppm (Reasonably homogeneous SEGs)

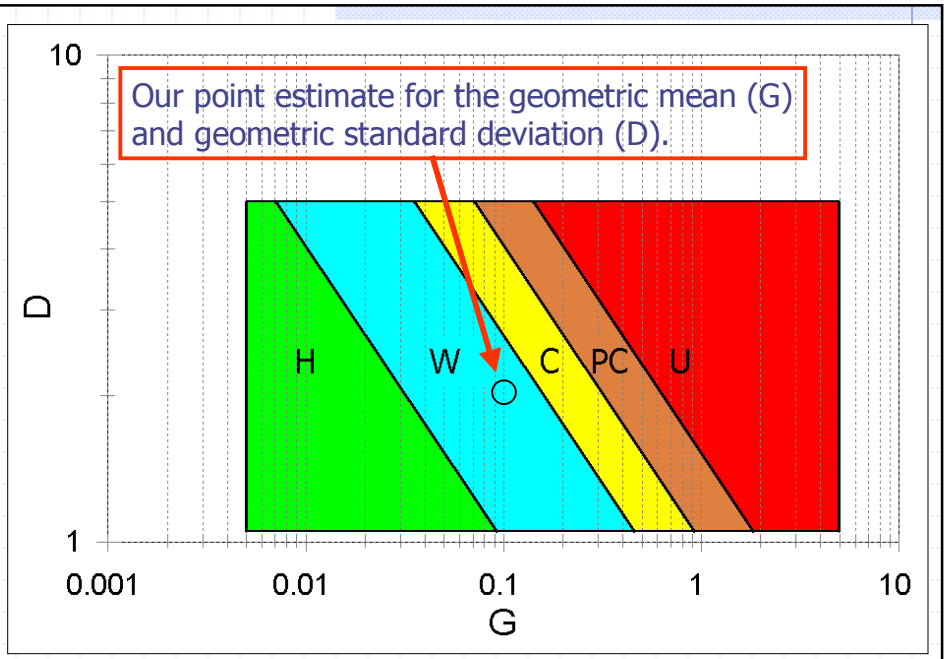


The Problem !

- How do we decide which rating zone best describes exposures in a particular work environment, and express our confidence in that decision?

Example – Conventional Analysis

- During a baseline/initial exposure assessment, an IH collected three (3) full-shift measurement from an SEG:
  - 0.05, 0.10, & 0.20 ppm
  - All were less than 50% of the 1 ppm TWA OEL.
- n = 3 ; gm = 0.10 ; gsd = 2.00
- The sample 95th percentile was 0.31 ppm,
- but with a 95%UCL of 20.2 ppm.



Example (cont'd)

- The point estimate of the 95th percentile is < 50% of the limit.
- Exposures *appear* to be in the well-controlled category.
- However, the 95%UCL($X_{0.95}$) is considerably greater than the OEL.
- What would you do?
  - Make a decision ?
  - Collect more data ?

Example (cont'd)

- Our IH concludes:
  - This operation is well-controlled with just the existing dilution ventilation.
  - Although the 95%UCLs were excessive, our IH took into account his extensive past experience with this type of operation.
- His recommendations:
  - Further sampling is not necessary.
  - Routine surveillance samples should be collected using the established schedule for well-controlled operations.

Summary: Conventional IH Data Analysis and Interpretation

- Rate the SEG.
- Collect *n* measurements per exposure group
- Estimate *group* statistics.
- Calculate the sample $X_{0.95}$ and its 95%UCL
- Compare to OEL (or exposure ratings)
- Mentally factor in professional judgment and experience, and reach a decision:
  - *Acceptable vs. Unacceptable*

  or
  - *HC, WC, C, PC, or UC*

The Bayesian Method

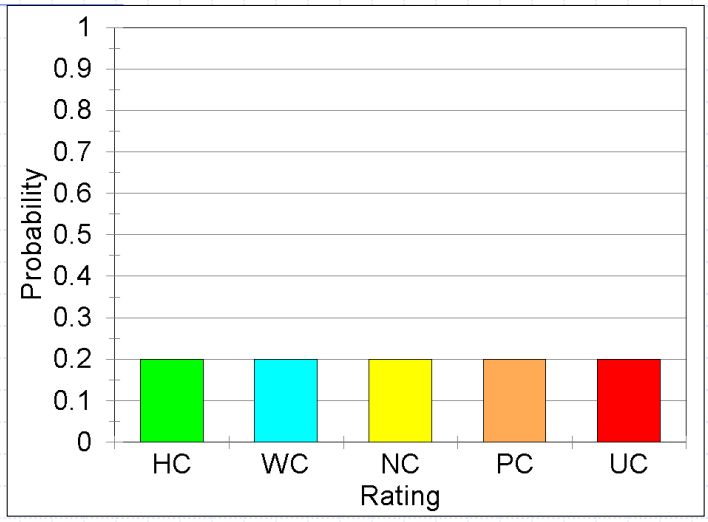
- Combining professional judgment (or other information) with our current data to reach a decision is a Bayesian process.
- Bayesian statistics – branch of statistics that acknowledges that *decisions* are rarely based upon the data alone.
- Is our IH a Bayesian statistician?

The Bayesian Method – Key Concepts

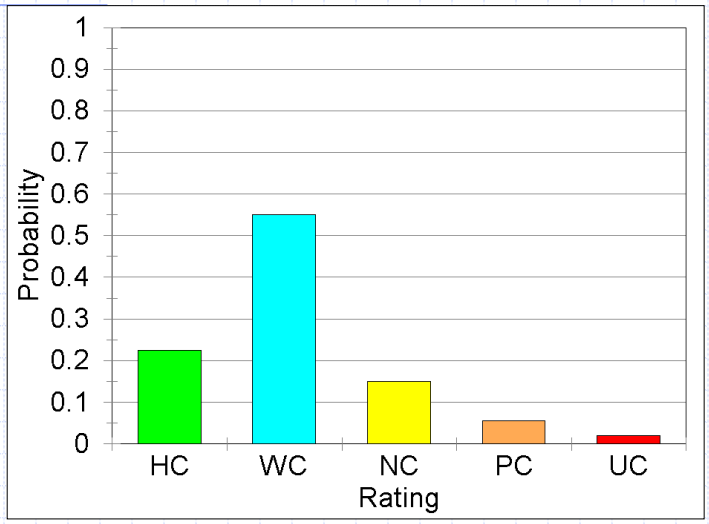
- Prior distribution*
  - Represents our expectation based upon professional judgment, past data, experience, modeling, etc.
  - Two types:
    - Non-informative prior - represents complete ignorance of the work environment
    - Informative prior – mathematically represents our judgment or experience with this work environment

* "Distribution" here refers to the distribution of decisions, not exposures.

Example – Non-informative Prior Distribution (no professional judgment)



Example – Informative Prior Distribution (professional judgment)

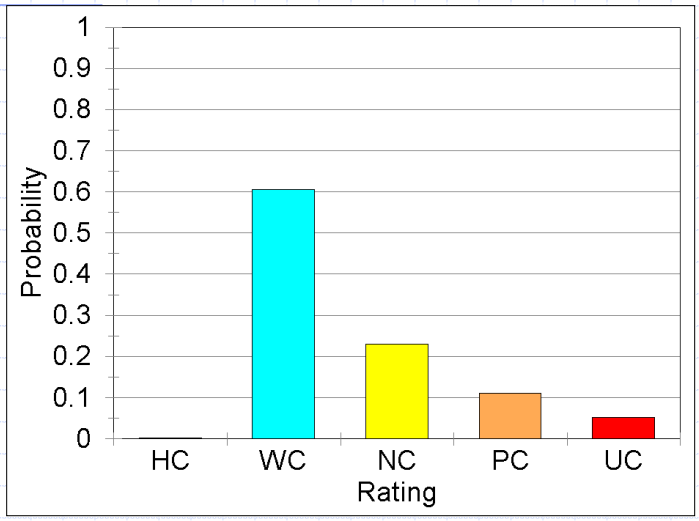


Key Concepts (cont'd)

- Likelihood distribution*
  - Estimates the decision probabilities using *only* the current data.

* "Distribution" here refers to the distribution of decisions, not exposures.

Example – Likelihood Distribution

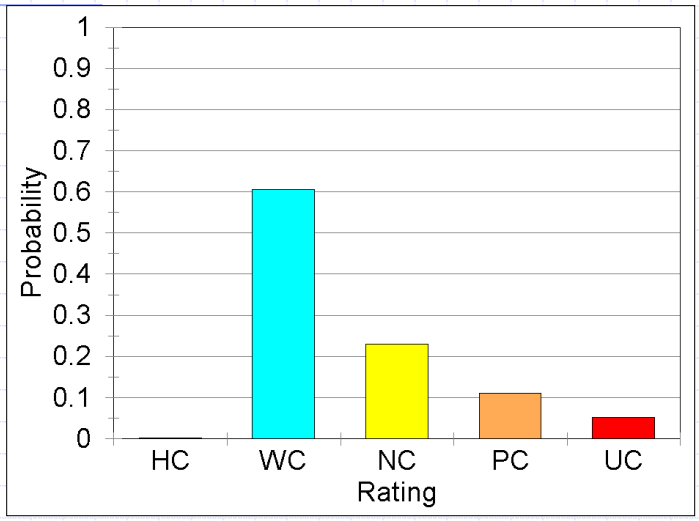


Key Concepts (cont'd)

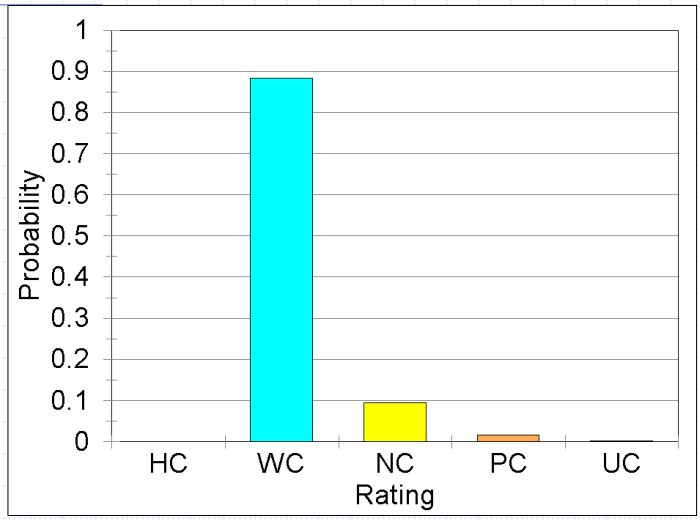
- Posterior distribution*
  - Represents our *final* decision probabilities.
  - It mathematically combines both our experience (represented by the prior distribution) and our data.
  - *If the likelihood distribution and our prior distribution are consistent*, then we can use the posterior distribution to reach a decision.

* "Distribution" here refers to the distribution of decisions, not exposures.

Example – Posterior Distribution (no professional judgment)



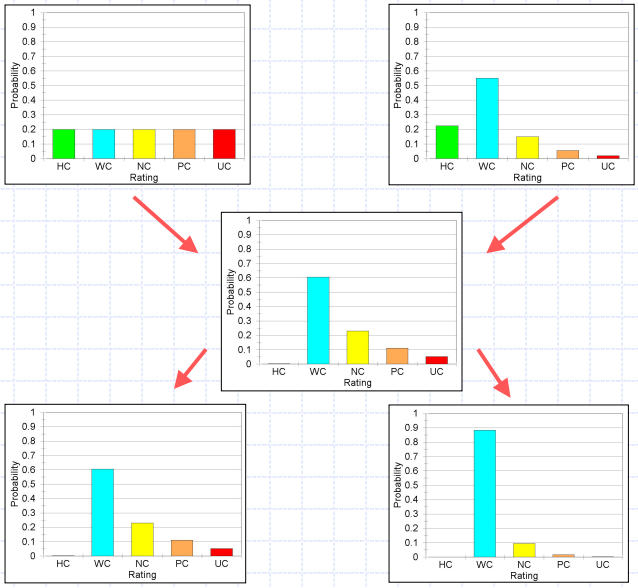
Example – Posterior Distribution (professional judgment)



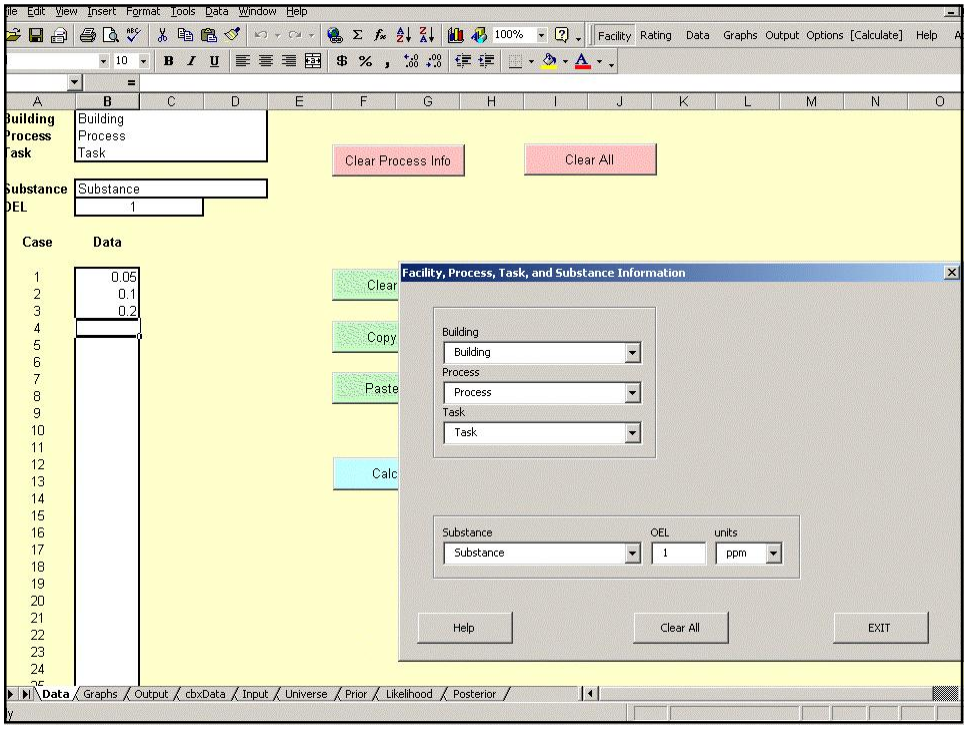
Non-informative

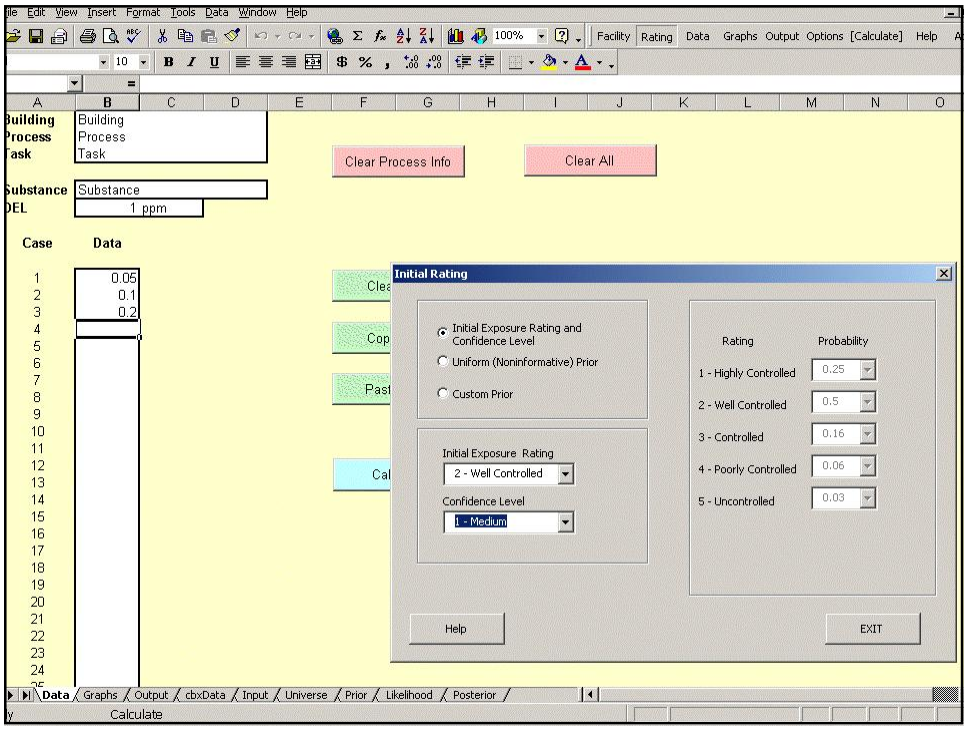
Informative

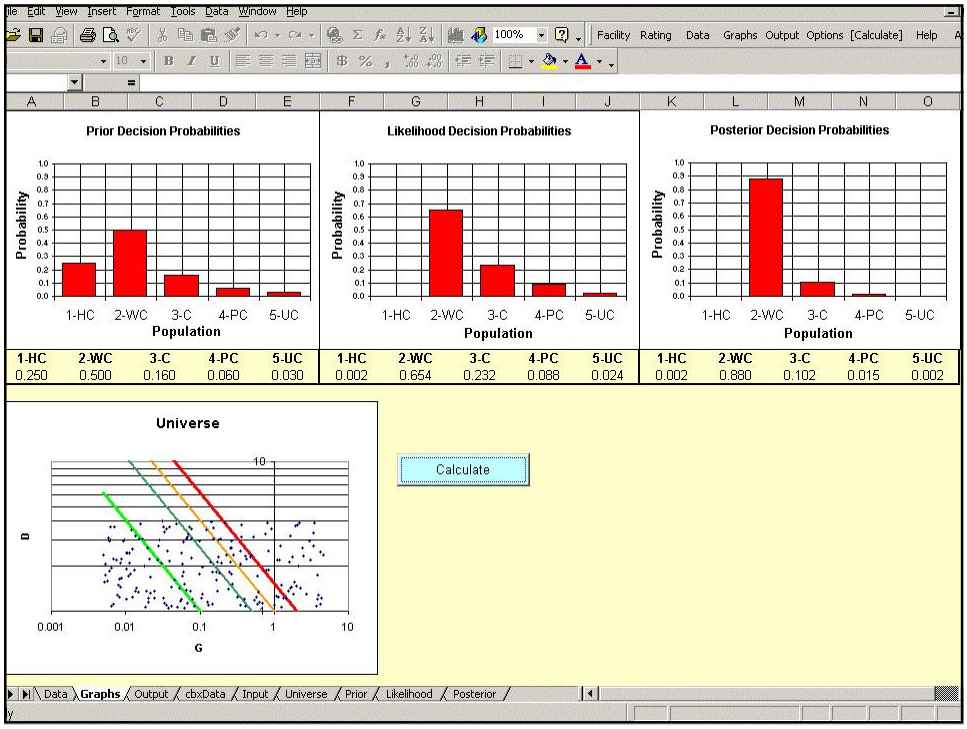
- Prior
- Likelihood
- Posterior

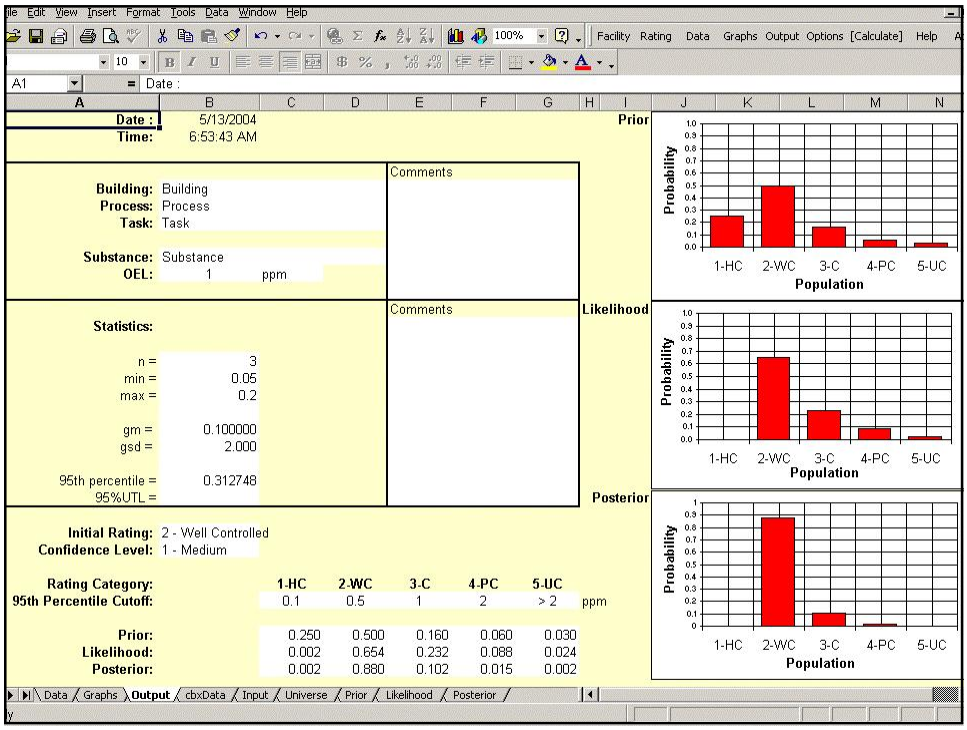


(go to BDA spreadsheet)

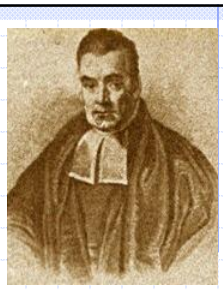

Facility Rating Data Graphs Output Options [Calculate] Help
Building
Process
Task
Substance
OEL
Clear Process Info
Clear All
Case
Data
Facility, Process, Task, and Substance Information
Building
Process
Task
Substance
OEL
units
ppm
Help
Clear All
EXIT
Data Graphs Output cbxData Input Universe Prior Likelihood Posterior


Facility Rating Data Graphs Output Options [Calculate] Help
Building
Process
Task
Substance
OEL
1 ppm
Clear Process Info
Clear All
Case
Data
Initial Rating
Initial Exposure Rating and Confidence Level
Uniform (Noninformative) Prior
Custom Prior
Rating
Probability
1 - Highly Controlled
2 - Well Controlled
3 - Controlled
4 - Poorly Controlled
5 - Uncontrolled
Initial Exposure Rating
Confidence Level
Help
EXIT
Data Graphs Output cbxData Input Universe Prior Likelihood Posterior
Calculate


Prior Decision Probabilities
Likelihood Decision Probabilities
Posterior Decision Probabilities
Probability
Population
1-HC 2-WC 3-C 4-PC 5-UC
1-HC 2-WC 3-C 4-PC 5-UC
0.250 0.500 0.160 0.060 0.030
0.002 0.654 0.232 0.088 0.024
0.002 0.880 0.102 0.015 0.002
Universe
D
G
Calculate
Data Graphs Output cbxData Input Universe Prior Likelihood Posterior


Date : 5/13/2004
Time: 6:53:43 AM
Building: Building
Process: Process
Task: Task
Substance: Substance
OEL: 1 ppm
Comments
Statistics:
n = 3
min = 0.05
max = 0.2
gm = 0.100000
gsd = 2.000
95th percentile = 0.312748
95%UTL =
Initial Rating: 2 - Well Controlled
Confidence Level: 1 - Medium
Rating Category: 1-HC 2-WC 3-C 4-PC 5-UC
95th Percentile Cutoff: 0.1 0.5 1 2 > 2 ppm
Prior: 0.250 0.500 0.160 0.060 0.030
Likelihood: 0.002 0.654 0.232 0.088 0.024
Posterior: 0.002 0.880 0.102 0.015 0.002
Prior
Likelihood
Posterior
Probability
Population
Data Graphs Output cbxData Input Universe Prior Likelihood Posterior

Foundation of BDA: Bayes' Theorem



Posterior Likelihood Prior

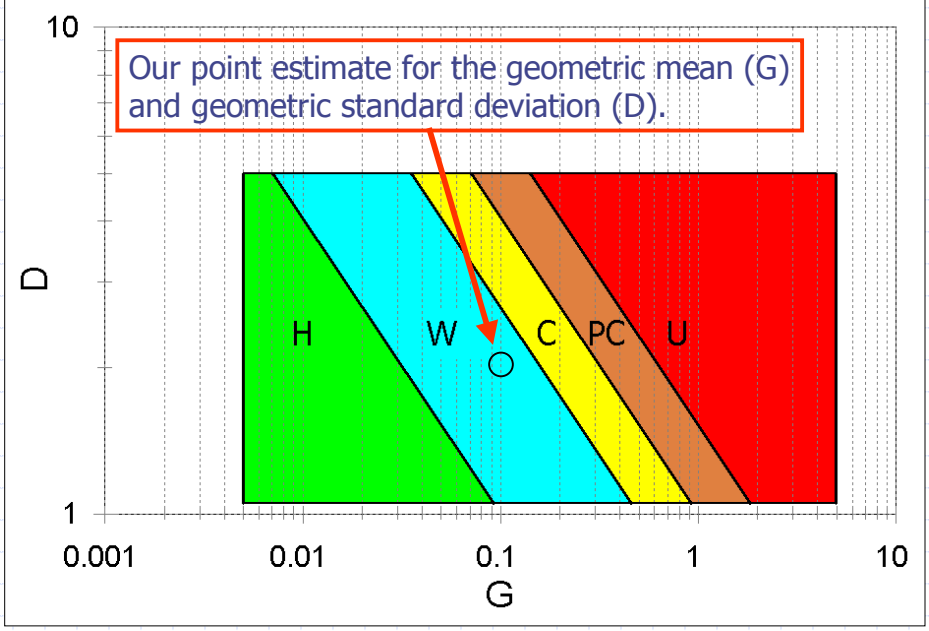
$$P(Pop_i|data) = \frac{P(data|Pop_i) \cdot P(Pop_i)}{\sum \left[P(data|Pop_i) \cdot P(Pop_i)\right]}$$

Correction Factor

Bayes' Theorem – Modified for this IH Application

$$P(Pop_i|data) = \frac{\int_{G_{\max}}^{G'} \int_{D_{\max}}^{D'} \left[P(data|G,D) \cdot P(Pop_i)\right] d(G)d(D)}{\int_{G_{\min}}^{G_{\max}} \int_{D_{\min}}^{D_{\max}} \left[P(data|G,D) \cdot P(Pop_i)\right] d(G)d(D)}$$

- Notes:
  - P(data|G,D) is calculated using the likelihood function.
  - The quantity P(data|G,D)*P(Pop_i) results in a 3D surface rising above the G and D 2D surface.
  - G' and D' refer to values that occur within each rating zone.



Potential Advantages of Bayesian Decision Making

- Professional judgment, experience, modeling, or other information can be explicitly and objectively incorporated into the calculations
- We can calculate the probability of each exposure rating.
- BDA enhances the interpretation of limited data, including datasets with censored data.

Bayesian Decision Analysis (cont'd)

- The BDA decision chart is easier to understand and communicate than our traditional statistics and confidence intervals.
- BDA has the potential to help us *calibrate* our initial ratings (i.e., our professional judgment).

Future Work

- Introduce BDA to the IH community via articles, presentations, PDCs, & software.
- Develop guidance for developing prior distributions.
- Develop guidance for handling inconsistent prior and likelihood distributions.
- In an industrial setting, apply and validate the general approach.

University of Minnesota and 3M Study Proposal

- Expert Decision-making in Occupational Exposure Assessment
  - Evaluate the accuracy of IH professional judgment in field settings
  - Identify the determinants of accurate professional judgment.
  - Examine the use of Bayesian Decision Analysis in improving professional judgment.
  - Develop a probabilistic framework for efficient decision-making.

Contact Information

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