Basic Level 1. PSA course for analysts

PSA quantification

Content

- Impacts of truncation on the numerical results
- Importance analysis
  - Roles and definitions
- Uncertainty analysis
  - Elements of the uncertainties

NUMERICAL TRUNCATION

IMPACTS FROM TRUNCATION

- OPTIMISTIC RESULTS
- DELETED CUTSETS
- INCONSISTENT CONTRIBUTORS
- INCORRECT IMPORTANCE MEASURES
- LEVEL OF DETAIL FOR APPLICATIONS
- LEVEL 1 / LEVEL 2 INTERFACE

NUMERICAL TRUNCATION
CONTROLLING TRUNCATION

- DO NOT ACCEPT RECOMMENDED CUTOFF VALUES
- ADJUST TRUNCATION LIMITS UNTIL RESIDUALS ARE LESS THAN ~ 10 % OF TOTAL
  - PER INITIATING EVENT
  - TOTAL CORE DAMAGE
- BETTER RESOLUTION MAY BE REQUIRED FOR SPECIFIC PLANT DAMAGE STATES OR LEVEL 2 ISSUES
- BETTER RESOLUTION MAY BE REQUIRED FOR SPECIFIC APPLICATIONS / SENSITIVITY STUDIES

NUMERICAL IMPORTANCE MEASURES
ROLE OF RISK IMPORTANCE MEASURES

- PROVIDE SIMPLE ESTIMATES OF SENSITIVITY TO EXTREME VALUES FOR MODEL PARAMETERS
- PROVIDE A SIMPLE AND COARSE RANKING OF ITEMS WITH RESPECT TO RISK OR SAFETY IMPORTANCE
- CAN BE USED TO FOCUS REVIEWS AND SENSITIVITY STUDIES
- SHOULD BE VIEWED AS A SUPPLEMENT TO, NOT A REPLACEMENT FOR, CAREFUL “TOP-DOWN” ANALYSIS OF THE RISK CONTRIBUTORS
- KNOWLEDGE OF THE MODEL IS ESSENTIAL TO AVOID MISLEADING CONCLUSIONS

NUMERICAL IMPORTANCE MEASURES
RISK INDICES AND MODEL ELEMENTS

- RISK INDICES
  - CORE DAMAGE FREQUENCY
  - LARGE, EARLY RELEASE FREQUENCY
  - EARLY FATALITY FREQUENCY
  - ANY OTHER RISK MEASURE WITHIN THE PSA MODEL SCOPE

- MODEL ELEMENTS
  - INITIATING EVENTS
  - SYSTEMS
  - HUMAN ACTIONS
  - COMPONENTS / INDIVIDUAL BASIC EVENTS
  - GROUPS OF BASIC EVENTS

NUMERICAL IMPORTANCE MEASURES
MOST COMMON IMPORTANCE MEASURES

- FRACTIONAL IMPORTANCE
- FUSSELL - VESELY IMPORTANCE
- BIRNBAUM IMPORTANCE
- RISK REDUCTION WORTH
- RISK ACHIEVEMENT WORTH

NUMERICAL IMPORTANCE MEASURES
VARIABLE DEFINITIONS

$R(Q_X = N)$ Calculated value of Risk Index R with the value of Model Element X set equal to its nominal Mean Value N.

$R(Q_X = 1)$ Calculated value of Risk Index R with the value of Model Element X set equal to 1.0.

$R(Q_X = 0)$ Calculated value of Risk Index R with the value of Model Element X set equal to 0.

NUMERICAL IMPORTANCE MEASURES
WARNING

- THE MATHEMATICAL FORMULAS FOR SOME NUMERICAL IMPORTANCE MEASURES ARE NOT DEFINED CONSISTENTLY IN THE LITERATURE
- THE “BASIC PHILOSOPHY” IS CONSISTENT
- DIFFERENCES PERTAIN PRIMARILY TO TREATMENT OF “SUCCESS STATES”

NUMERICAL IMPORTANCE MEASURES
FRACTIONAL IMPORTANCE

- MEASURE OF THE FRACTION OF RISK INDEX R THAT IS CONTRIBUTED BY FAILURE OF MODEL ELEMENT X

- GENERAL DEFINITION

$$FI_X = SUM\ (\text{All cutsets with X failed}) \ / \ R(Q_X = N)$$

- RISK SPECTRUM DEFINITION (SAME AS FUSSELL - VESELY IMPORTANCE)

$$FI_X = [\, R(Q_X = N) - R(Q_X = 0)\,] \ / \ R(Q_X = N)$$

NUMERICAL IMPORTANCE MEASURES
FUSSELL - VESELY IMPORTANCE

- MEASURE OF THE FRACTION OF RISK INDEX R THAT IS CONTRIBUTED BY FAILURE OF MODEL ELEMENT X

- GENERAL DEFINITION

$$FV_X = [\, R(Q_X = N) - R(Q_X = 0)\,] \;/\; R(Q_X = N)$$

- RISK SPECTRUM DEFINITION

$$FV_X = [\, R(Q_X = N) - R(Q_X = 0)\,] \;/\; R(Q_X = N)$$

NUMERICAL IMPORTANCE MEASURES
BIRNBAUM IMPORTANCE

- MEASURE OF THE MAXIMUM POSSIBLE FRACTIONAL CONTRIBUTION TO RISK INDEX R FROM FAILURE OF MODEL ELEMENT X. (SOMETIMES CALLED THE PARTIAL RISK DERIVATIVE FOR ELEMENT X.)

- GENERAL DEFINITION

$$BI_X = [\, R(Q_X = 1) - R(Q_X = 0) \,] \; / \; R(Q_X = N)$$

- RISK SPECTRUM DEFINITION - NOT CALCULATED

NUMERICAL IMPORTANCE MEASURES
RISK REDUCTION WORTH

- MEASURE OF THE AMOUNT BY WHICH RISK INDEX R MAY BE REDUCED IF MODEL ELEMENT X IS PERFECT

- GENERAL DEFINITION (INVERTED IN SOME REFERENCES)

$$RRW_X = R(Q_X = N) \;/\; R(Q_X = 0)$$

- RISK SPECTRUM DEFINITION

$$RRW_X = R(Q_X = N) \;/\; R(Q_X = 0)$$

NUMERICAL IMPORTANCE MEASURES
RISK ACHIEVEMENT WORTH

- MEASURE OF THE AMOUNT BY WHICH RISK INDEX R MAY INCREASE IF MODEL ELEMENT X IS ALWAYS FAILED

- GENERAL DEFINITION (INVERTED IN SOME REFERENCES)

$$RAW_X = R(Q_X = 1) \;/\; R(Q_X = N)$$

- RISK SPECTRUM DEFINITION

$$RAW_X = R(Q_X = 1) \;/\; R(Q_X = N)$$

NUMERICAL IMPORTANCE MEASURES
USE OF RISK IMPORTANCE MEASURES

- USED TO IDENTIFY COMMON CONTRIBUTORS THAT APPEAR IN MANY SEQUENCES AND CUTSETS
- USED FOR RANKING PLANT FEATURES BY RISK SIGNIFICANCE (E.G., FOR FOCUSED TESTING OR MAINTENANCE)
- RISK ACHIEVEMENT WORTH IS USEFUL FOR ESTIMATING THE RISK SIGNIFICANCE OF EQUIPMENT THAT IS REMOVED FROM SERVICE
- RISK REDUCTION WORTH IS USEFUL FOR BOUNDING THE RISK BENEFITS FROM PROPOSED IMPROVEMENTS
- IMPACTS FROM SOME PRECURSOR EVENTS CAN BE EVALUATED BY EXAMINATION OF IMPORTANCE MEASURES
- EXAMINATION OF GROUPS CAN PROVIDE INSIGHTS ABOUT COMPOUND IMPACTS AND DEPENDENCIES NOT EVIDENT FROM SINGLE-COMPONENT ANALYSES

NUMERICAL IMPORTANCE MEASURES

COMMON PROBLEMS IN USE OF RISK IMPORTANCE

- IMPACTS FROM NUMERICAL TRUNCATION
- ARTIFICIAL ASYMMETRIES IN MODELS FOR NORMALLY RUNNING EQUIPMENT
- LIMITATIONS IN SIMULATING EQUIPMENT OUT OF SERVICE (GUARANTEED FAILED)
- LIMITATIONS IN SIMULATING “SUCCESS STATES”
- NO CONSIDERATION OF UNCERTAINTIES; DETAILED NUMBERS IMPLY THAT ALL VALUES ARE KNOWN PRECISELY
- FOCUS TOO MUCH ATTENTION ON NUMERICAL COMPARISONS OF FINE STRUCTURE, RATHER THAN “BIG PICTURE” UNDERSTANDING OF RISK CONTRIBUTORS

UNCERTAINTY

WHY DO WE CARE ABOUT UNCERTAINTY?

- HAZARD VS. RISK
- BOUNDING VS. REALISTIC
- DECISION MAKING
- ROLE OF COMMUNICATION IN RISK ASSESSMENT

SOURCES OF UNCERTAINTY

- DATA
- MODEL
- APPLICATION OF THE MODEL

UNCERTAINTY

DATA UNCERTAINTY

- INTERPRETATION AND CLASSIFICATION OF FAILURE EVENTS
- DETERMINATION OF SUCCESS DATA (NUMBER OF DEMANDS, OPERATING HOURS, EXPOSURE TIME, ETC.)
- SIZE OF DATA SAMPLE (STATISTICAL UNCERTAINTY)
- APPLICABLE POPULATION
- MATHEMATICAL MODELS FOR DATA ANALYSIS

UNCERTAINTY

CORRELATED UNCERTAINTIES

- COMMON DATA FOR SEVERAL COMPONENTS / FAILURE MODES
- INDEPENDENT SAMPLING REDUCES OVERALL UNCERTAINTY
- ACCOUNT FOR CORRELATION TO MAINTAIN CORRECT UNCERTAINTY
- MEAN VALUE OF $(A)^2$ =/= (MEAN VALUE OF $A)^2$

UNCERTAINTY

MODEL UNCERTAINTY

- SCOPE
- COMPLETENESS
- SUPPORTING DOCUMENTATION AND ANALYSES
- SUCCESS CRITERIA
- ASSUMPTIONS
- ERRORS

UNCERTAINTY

MODEL SCOPE

- LEVEL 1, LEVEL 2, LEVEL 3
- FULL-POWER OPERATION, LOW POWER, SHUTDOWN
- INTERNAL EVENTS, EXTERNAL EVENTS

UNCERTAINTY

MODEL SCOPE (Cont.)

- WE CAN MAKE VERY LIMITED STATEMENTS ABOUT OUR STATE OF KNOWLEDGE WITH RESPECT TO PUBLIC HEALTH RISK IF WE HAVE PERFORMED ONLY A LEVEL 1 PSA THAT ESTIMATES THE FREQUENCY OF CORE DAMAGE DUE TO INTERNAL INITIATING EVENTS DURING FULL-POWER OPERATION.

UNCERTAINTY

MODEL COMPLETENESS

- INITIATING EVENTS
- PHENOMENA
- DEPENDENCIES
- HUMAN PERFORMANCE

UNCERTAINTY

INITIATING EVENTS

- SUPPORT SYSTEMS
- “INSIGNIFICANT” INITIATORS
- RECOMMENDED TREATMENT
  - ESTIMATE FREQUENCY
  - DETERMINE FUNCTIONAL IMPACTS
  - ALLOW PSA MODEL TO QUANTIFY ITS SIGNIFICANCE

UNCERTAINTY
PHENOMENA

- FAILURE TO SCRAM (ATWS)
- OVERCOOLING (PTS)
- TRANSIENT-INDUCED EVENTS (LOCA, LOSP, ETC.)
- CONTAINMENT PHENOMENA (HYDROGEN, STEAM, AEROSOLS, ETC.)
- RECOMMENDED TREATMENT
  - INCLUDE IN MODEL, IF POSSIBLE
  - BOUND FUNCTIONAL IMPACTS IF NOT MODELED EXPLICITLY
  - SENSITIVITY STUDIES CAN ESTIMATE NUMERICAL CONSERVATISM

UNCERTAINTY

DEPENDENCIES

- PHYSICAL
- FUNCTIONAL
- LOCATION / ENVIRONMENTAL
- DATA-BASED
- HUMAN

UNCERTAINTY
SUPPORTING DOCUMENTATION AND ANALYSES

- PLANT DESIGN INFORMATION
- OPERATING, TESTING, MAINTENANCE PROCEDURES
- DESIGN-BASIS ACCIDENT ANALYSES
- BEST-ESTIMATE THERMAL / HYDRAULIC ANALYSES
- RECOMMENDED TREATMENT
  - “FIRST PRINCIPLES” CALCULATIONS
  - DOCUMENT AND QUANTIFY UNCERTAINTY
  - BOUND FUNCTIONAL IMPACTS IF NOT MODELED EXPLICITLY
  - SENSITIVITY STUDIES CAN ESTIMATE NUMERICAL CONSERVATISM

UNCERTAINTY

SUCCESS CRITERIA

- SYSTEMS
- OPERATOR ACTIONS
- RECOMMENDED TREATMENT
  - BEST-ESTIMATE ANALYSES
  - BOUNDING ASSUMPTIONS
  - SENSITIVITY STUDIES CAN ESTIMATE NUMERICAL CONSERVATISM

UNCERTAINTY

ASSUMPTIONS

- DOCUMENT ALL ASSUMPTIONS
- SENSITIVITY STUDIES CAN ESTIMATE NUMERICAL CONSERVATISM

UNCERTAINTY

ERRORS

- THERE ARE ERRORS IN YOUR STUDY
- SOME ERRORS PRODUCE CONSERVATIVE RESULTS, AND SOME PRODUCE OPTIMISTIC RESULTS
- TYPICAL REVIEWS TEND TO FIND ERRORS THAT PRODUCE CONSERVATIVE RESULTS
- TYPICAL REVIEWS TEND TO MISS ERRORS THAT PRODUCE OPTIMISTIC RESULTS
- REVIEWS SHOULD EXAMINE "WHAT IS NOT IMPORTANT" WITH EQUAL EMPHASIS AS "WHAT IS IMPORTANT"
- DEVELOP CONFIDENCE AND UNDERSTANDING WHY SPECIFIC INITIATING EVENTS, SCENARIOS, AND CONDITIONS ARE NOT IMPORTANT
- ANALYST KNOWLEDGE, SENSITIVITY STUDIES, AND IMPORTANCE ESTIMATES CAN HELP TO FOCUS EXAMINATION

UNCERTAINTY

SUMMARY

- COMMUNICATION IS A CENTRAL ELEMENT OF RISK ANALYSIS AND DECISION MAKING
- WE HAVE NOT COMPLETED OUR JOB AS RISK ANALYSTS UNTIL WE HAVE ADDRESSED UNCERTAINTY
- BETTER A SIMPLIFIED QUANTITATIVE, OR EVEN QUALITATIVE, UNCERTAINTY ANALYSIS THAN NOTHING