Software Reliability and Safety

CSE 8317 — Fall 2008

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SSE.2: Hazard Analysis & Resolution

- Hazard Analyses and Techniques
- HA Techniques: FTA and ETA
- Hazard Resolution
- Damage Reduction

Safety Analysis

- Hazard and risk identification:
  - ▷ Accident scenarios: actual/hypothetical – starting points for safety
  - ▷ Focus: operations and operational env.

- Hazard analysis and assessment:
  - ▷ Fault trees: (static) logical conditions
  - ▷ Event trees: dynamic sequences
  - ▷ Other analyses/assessment techniques

- Hazard and risk resolution
  - ▷ Hazard elimination
  - ▷ Hazard reduction
  - ▷ Hazard control
  - ▷ Damage control

Hazard Analyses: Types

- Sub-system hazard analyses (SSHA)
  - ▷ Hazard within individual sub-system
  - ▷ Component/sub-system in isolation
- System hazard analyses (SHA)
  - ▷ Focus: interface and interaction
  - ▷ Subsys/env/human effect on system
  - ▷ Throughout development process
  - ▷ Focus on early phases to provide info. for other activities (hazard resolution and safety verification)
- SHA/SSHA in software process
  - ▷ Throughout development process
  - ▷ Focus on early phases to provide info. for other activities (hazard resolution and safety verification)

Hazard Analyses: Techniques

- Primary techniques for SHA/SSHA:
  - ▷ Fault-tree analyses (FTA)
  - ▷ Event-tree analyses (ETA)
  - ▷ SQE Ch.16.4 and Safeware Ch.14.

- Other techniques:
  - ▷ Design reviews & checklists
  - ▷ Hazard indices
  - ▷ Risk trees
  - ▷ Cause-consequence analysis (CCA)
  - ▷ Hazard & operability analysis (HAZOP)
  - ▷ Failure modes and effect analysis, etc.
  - ▷ Above: “Safeware” Ch.14.
  - ▷ Specific to software: “Safeware” Ch.15.

- FTA and ETA slides from SQE Ch.16.4.

Hazard Analysis: SFTA

- SFTA: Software FTA
  - ▷ Same concept applied to software
  - ▷ Actual implementation (white-box)
  - ▷ Language elements (high-level):
    - – assignment and function calls
    - – branching statement, loops, etc.
  - ▷ Also for specification/architecture
    - – black-box control flow diagram
    - – equivalent language representation

- SFTA construction:
  - ▷ Templates/examples for diff. statements
  - ▷ Safeware 18.2.2 (pp.497-507)

⇒ Additional work needed,
especially for system design/architecture

Hazard Analysis: ETA & CCA

- ETA alone: trace of accident.
  May desire explanation also (from FTA)

- Cause-consequence diagram (CCA):
  - ▷ Combine ETA with FTA
  - ▷ Explaining decisions in ET

- Using ETA and CCA:
  - ▷ Partial vs. total ETA
  - ▷ Focus on main consequences
  - ▷ Details:
    "Safeware" 14.5-14.6 (pp.327-pp.335)

Hazard and Risk Resolution

- Generic hazard resolution techniques (in order of their precedence):
  - ▷ Hazard elimination:
    – eliminate hazard sources
  - ▷ Hazard reduction:
    – reduce hazard likelihood/severity
  - ▷ Hazard control:
    – control hazard severity/scope

- Hazard resolution $\Rightarrow$ prob(accident) $\downarrow$

- Related issues:
  - ▷ Basis: hazard identification and analysis via FTA, ETA, CCA, etc.
  - ▷ Many specific techniques
  - ▷ Related to QA and SRE
  - ▷ Risk resolution: damage reduction too

Hazard Elimination

- Elimination of hazard
  - ▷ Intrinsically safe (sub-)system
  - ▷ All eliminated: feasibility & cost?
  - ▷ Certain types of hazard eliminated
  - ▷ Direct use of hazard identification and analysis results.

- Specific techniques: "Good SE & SSE"
  - ▷ Component substitution ($\Leftarrow$ FTA)
  - ▷ No single point of failure ($\Leftarrow$ ETA)
  - ▷ Simplification of building blocks
  - ▷ Decoupling of system architecture
  - ▷ Human errors/hazardous material elim.
  - ▷ Component safety certification:
    - – formal verification
    - – components identified by FTA etc.
  - ▷ Link to testing/FT/QA activities

Hazard, Controllability, & Observability

- Related to hazard resolution, particularly hazard reduction and control.

- Controllability:
  - ▷ Between any two system states
  - ▷ Desirable/safe states: maintain
  - ▷ Fail ⇒ action ⇒ safe (haz. control)
  - ▷ Controllability limits:
    - – system design/structure limit
    - – energy/capacity limit

- Observability: observation of system states (and failures), basis for control.

Design for Controllability

- Maintain safe states
  - ▷ Use built-in control
  - ▷ Monitoring: observation $\Rightarrow$ control
  - ▷ Multiple checks $\Leftarrow$ monitoring
  - ▷ Mostly in hazard reduction
- Enhancing control opportunities:
  - ▷ Incremental control: more control points
  - ▷ Intermediate states: more obs. points ($\Rightarrow$ more control opportunities)
  - ▷ Decision aid: easier/more control points
  - ▷ Both in hazard reduction and especially in hazard control

Hazard Reduction

- Hazard reduction:
  - ▷ Severity reduction:
    - – change failure characteristics (failure $\wedge \neg$ hazard)
    - – various locks/barriers
  - ▷ Likelihood reduction:
    - – reduce failure probability
    - – in combination with above
    - – also: most QA/SRE related techniques

- Specific techniques:
  - ▷ Design for controllability
  - ▷ Barriers and locks (passive)
  - ▷ Failure/hazard probability/severity $\downarrow$ (accident probability$\downarrow$)

Hazard Reduction: Techniques

- Monitoring and checks: Fig 16.2
  - ▷ Hardware checks: lowest level
  - ▷ Code-level checks: assertions
    – connection to PSC (SSE.4)
  - ▷ Audit checks: independent monitoring
  - ▷ Supervisory checks: system/highest level

- Locks and barriers (passive)
  - ▷ Lock-outs (preventing hazard)
  - ▷ Lock-ins (maintaining safety conditions)
  - ▷ Interlocks (correct order/combinations)
  - ▷ Other barriers (extra cap./redundancy/etc.)

Hazard Reduction: Techniques

- Hazard probability minimization:
  - ▷ Design with extra capacity:
    - safety factors/margins example
    - melt temp. T_m and margin M
    - $\Rightarrow$ safety bound $T_s = T_m - M$
  - ▷ Redundancy: similar
  - ▷ QA and SRE: failure ↓
    - focused hazard probability min.
    - with FTA/ETA/etc. help

- Redundancy (FT etc.) $\Rightarrow$ prob(hazard) ↓:
  - ▷ Hardware redundancy/backup
  - ▷ Software redundancy:
    - fault tolerance (NVP, & (?) RB)
    - anticipated input/env. enlargement
    - "fool-proof" software
  - ▷ Recovery: similar to RB in FT
  - ▷ Hardware/software interlocks

Hazard Resolution: Hw/Sw Interlock

- Interlock software
  - ▷ Software used as safety interlock
    - (s/w usage: data/control/safety)
    - example: emergency shut-down s/w
  - ▷ More stringent safety requirement:
    - most s/w function safety-related
    - should not rely solely on s/w
    - Therac-25 accident lessons

- Hardware/software interlock
  - ▷ Limitation of s/w backups:
    - diversity and independence problems
  - ▷ Hardware backups and interlocks:
    - different characteristics
    - different failure mechanisms
    - more likely to be *independent*
    - passive/active safety devices
  - ▷ Combine the advantages ⇒ safety ↑

Hazard Control

- Hazard control:
  - ▷ Detecting hazard, then control it
  - ▷ Built-in control: by design
  - ▷ Change after detection:
    - – (passive) limits
      (mostly outside system)
    - – (active) control devices/sub-systems

- Specific techniques:
  - ▷ Limiting exposure (duration$\downarrow$)
  - ▷ Isolation and containment
  - ▷ Protection systems
  - ▷ Fail-safe design

Hazard Control: Techniques

- Internal system change:
  - ▷ Isolation of hazard event
  - ▷ Containment around hazard event
  - ▷ Fail-safe design (passive)

- System augmentation:
  - ▷ Protection system (PS) added on:
    - hazard ⇒ PS action ⇒ safe
    - shut-down or partial shut-down
    - e.g., automatic coolant injection or pressure relief
  - ▷ Controllability limit (earlier)
  - ▷ Partial solution may be necessary:
    - reduce the severity
    - bring to a neighboring state

Risk Resolution: Damage Reduction

- Damage reduction: Why?
  - ▷ Risk factors:
    f(prob(haz), prob(haz$\rightarrow$acc), damage)
  - ▷ All the hazard resolution techniques
    $\Rightarrow$ risk $\neq 0$ still!
  - ▷ Damage reduction needed
  - ▷ Passed “point of no return”

- Specific techniques:
  - ▷ Escape routes (lifeboats, fire escapes, evacuation plans, etc.)
  - ▷ Safe abandonment (haz. waste disposal)
  - ▷ Devices for limiting damage:
    – auto safety devices
    – limited melt-down
    – collapsible signpost, etc.

Perspectives

- SSE: Augment S/w Eng.
  - ▷ Analysis to identify hazard
  - ▷ Design for safety
  - ▷ Verify safety constraints (next module)
  - ▷ Leveson's s/w safety program

- Dealing with hazard/risk in SSE:
  - ▷ Hazard identification and analysis
  - ▷ Design for safety/hazard resolution:
    - – Hazard elimination/reduction/control
  - ▷ Damage reduction
  - ▷ Safety verification
  - ▷ All in SSE context: hazard focus.