End-to-End Fault Management Analysis Method, Results and Future Improvements

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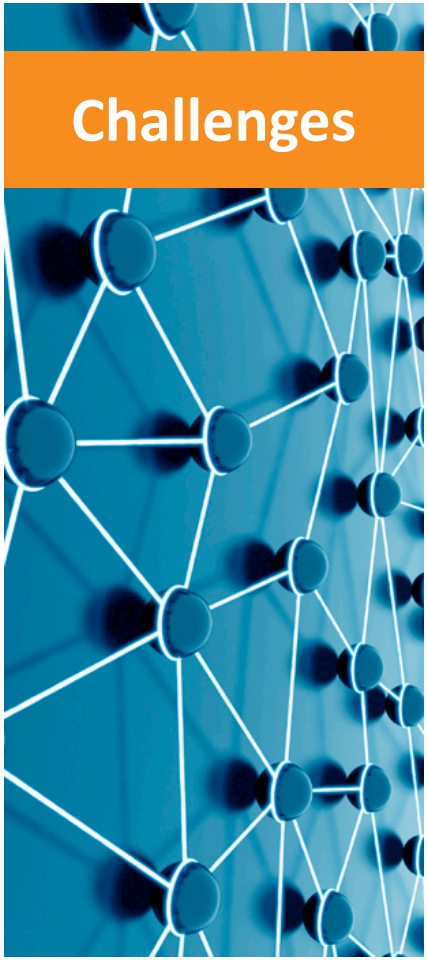
Completion and Conflicts,
Identifying the Problematic “Unknown Unknowns”

Agenda

- Challenges
  - Overview
  - FM Assurance Goals
  - IV&V Assurance Questions
  - 2D State-Space Representation
- Proposed Approach
  - Overview
  - Traceability Process
  - System Model Generation Process
  - Conflict Analysis Process
  - Example
- Status and Results
- Future Efforts and Conclusions
- Acronyms/Abbreviations

Challenges: Overview

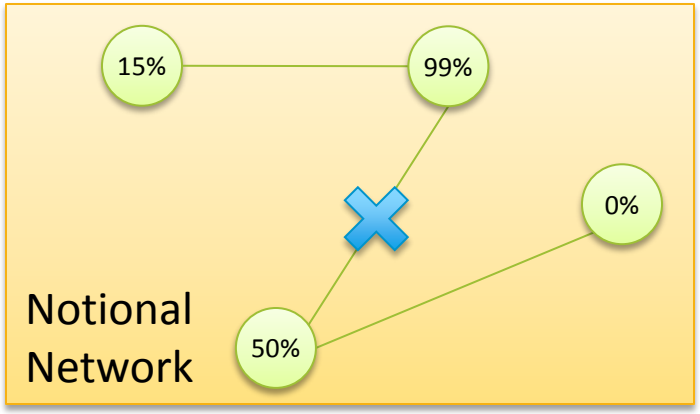


- Provide SW Assurance for a large, distributed and fault-tolerant system
  - Local and Global responses
  - Need to balance asset safety with mission objectives
- Subsystems have varying lifecycles and development organizations
- Providing and maintaining assurance up to launch (and beyond)
- Automated or scripted responses/sequences are not governed by “requirements” and are implemented late in system lifecycle.
- 100% Verification/Assurance/Success cannot be guaranteed
  - How much assurance is enough?
  - How do we provide efficient and effective SW assurance?

Challenges: FM Assurance Goals

FM Validation Goals

- List of Failures are complete
- List of Effects (Impacts) are complete
- List of Controls/Mitigation complete for each Fault
- Able to meet mission/user needs
- List of (FM) requirements complete



FM Verification Goals

- Every FM requirement met
- FM system responds in time to prevent Failure Propagation (i.e. domino effect)
- FM system isolates failures (i.e. allow other objectives to continue, Failure Containment)
- FM system effectively diagnoses the problem and limits effects to healthy systems
- Known dependencies for each Control to other systems, other controls, etc
- FM system is free from conflicts within controls and other systems

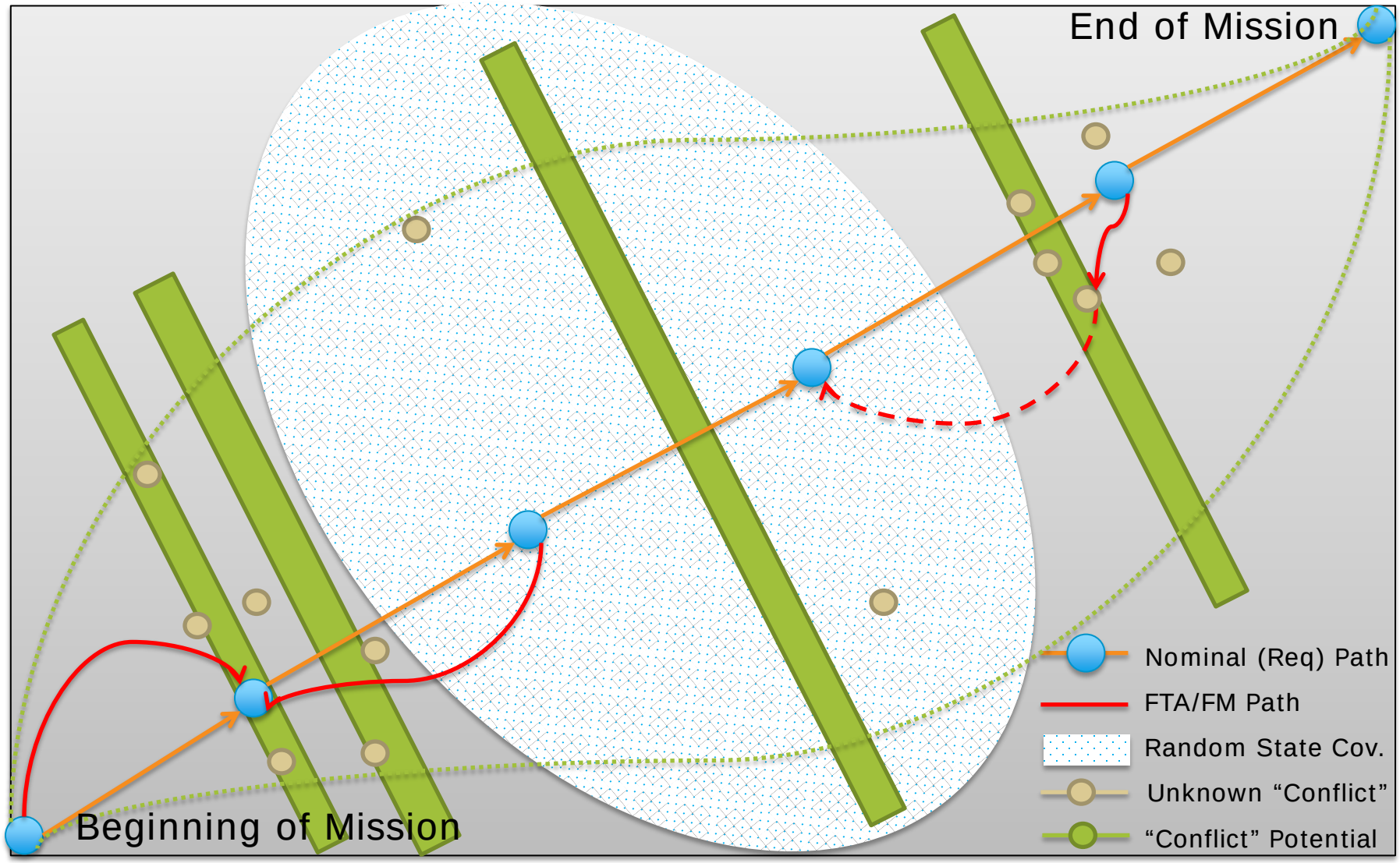
Challenges: IV&V Assurance Questions

- Is the (FM) system implemented correctly (Q1/Q2)?
  - Assuming that every component of the FM system is tied to a requirement, normal IV&V activities will answer this question as it relates to Q1 for each component.
  - Q2 is harder to address because we must check the entire system as a whole to determine if there are conflicts between the components.

- Does the FM system behave correctly under adverse conditions?
  - Difficult to answer without determining all credible adverse conditions (off-nominal/failure scenarios). Two options exist:
    - 1) Brute Force/Bottoms-Up/Testing - Throw every possible scenario at the system and "catch" problems.
    - 2) Top-Down - Identify the conflicts you want to prevent (assume this is complete) see if any credible scenario exists to reach this point.
    - Proposal - 3) Intermediate – Using limited bottoms-up and top-down approach, determine potential conflicts and work backwards to find a credible scenario or eliminate the conflict as not possible.

Goal: Identify more problem scenarios than top-down approach without the cost of full bottoms-up approach

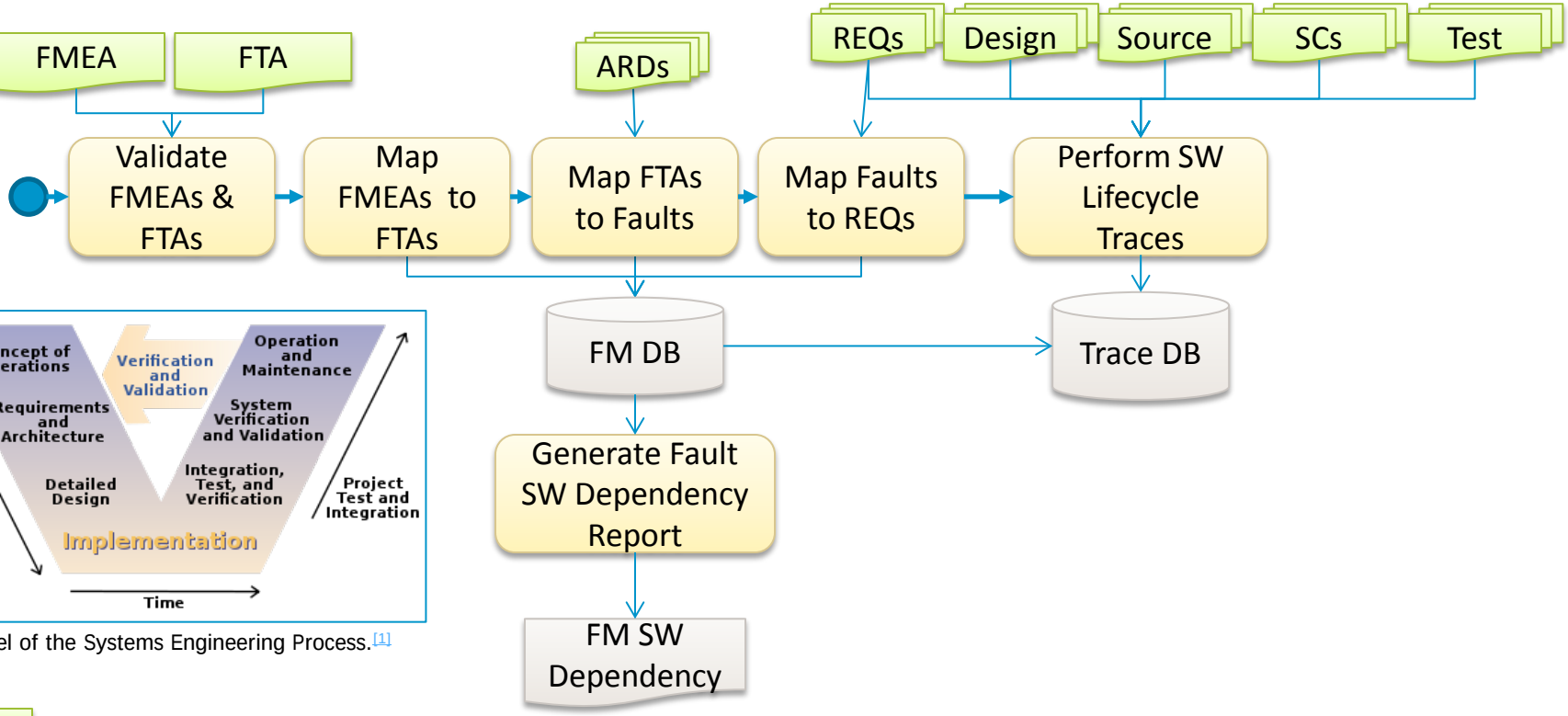
Challenge: 2D State-Space Representation

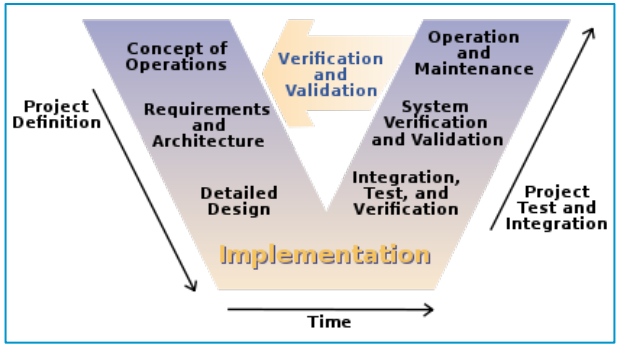


Proposed Approach: Overview

- Top-Down: develop conflict rules based on user/mission needs and known failure modes
- Bottoms-Up: develop low to medium fidelity model of the system (Event Network)(emphasis on software perspective) (Reduced state-space)
- Apply automated/scripted principles to establish scenario coverage of the system model
- Automated static analysis will eliminate scenarios where conflict is not possible and highlight those with potential/suspected conflict
- Manual analysis will determine scenario credibility of suspected conflicts
- High-fidelity simulations, tests, and analysis used to confirm conflicts
- Approach Relies on:
  - Relational Database, FM Traceability, System State Models, Event Network, Conflict Rules, and High-Fidelity Simulator / test bed

Proposed Approach: Traceability Process





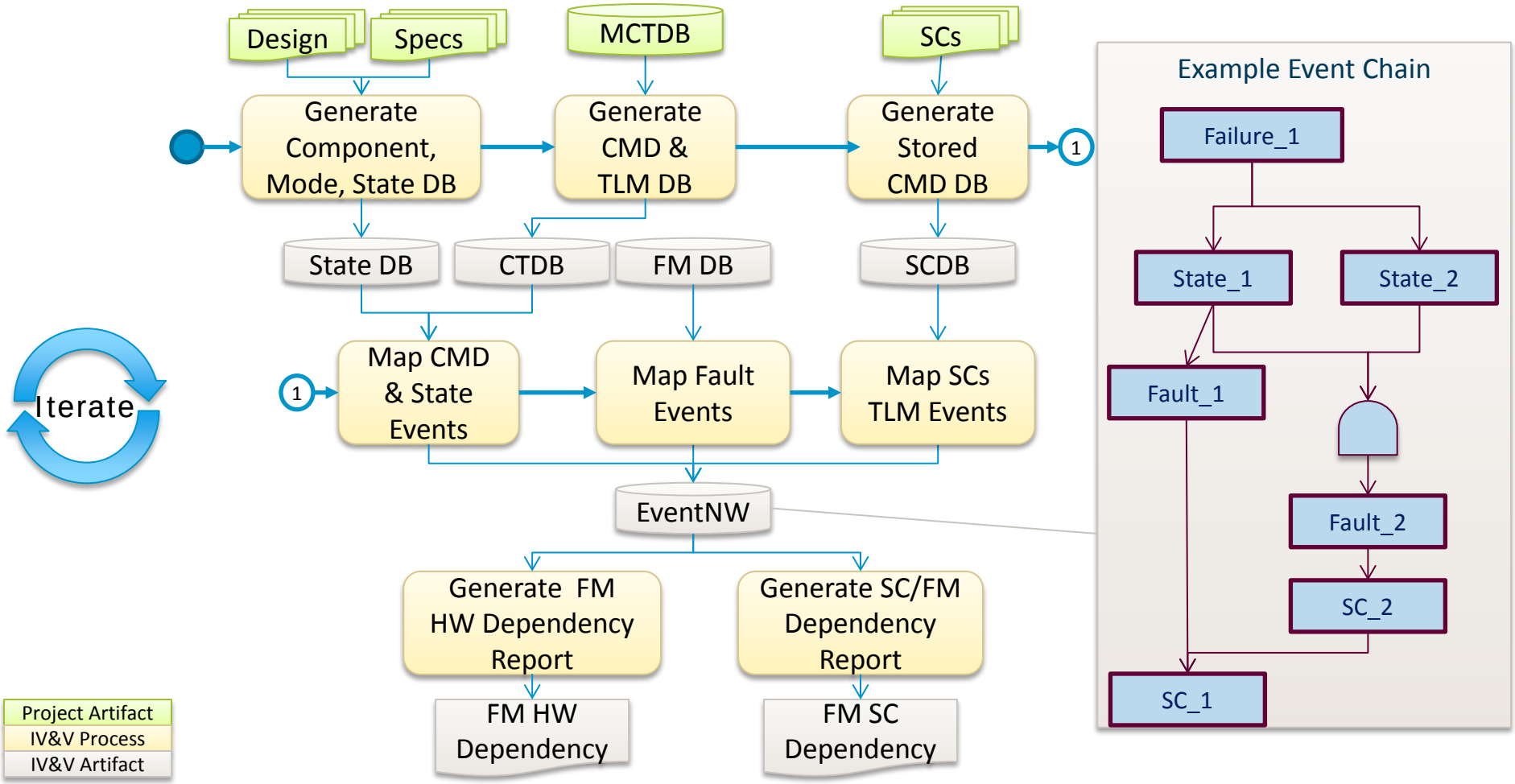
The V-model of the Systems Engineering Process.[1]

Project Artifact
IV&V Process
IV&V Artifact

End-to-End FM analysis requires End-to-End traceability

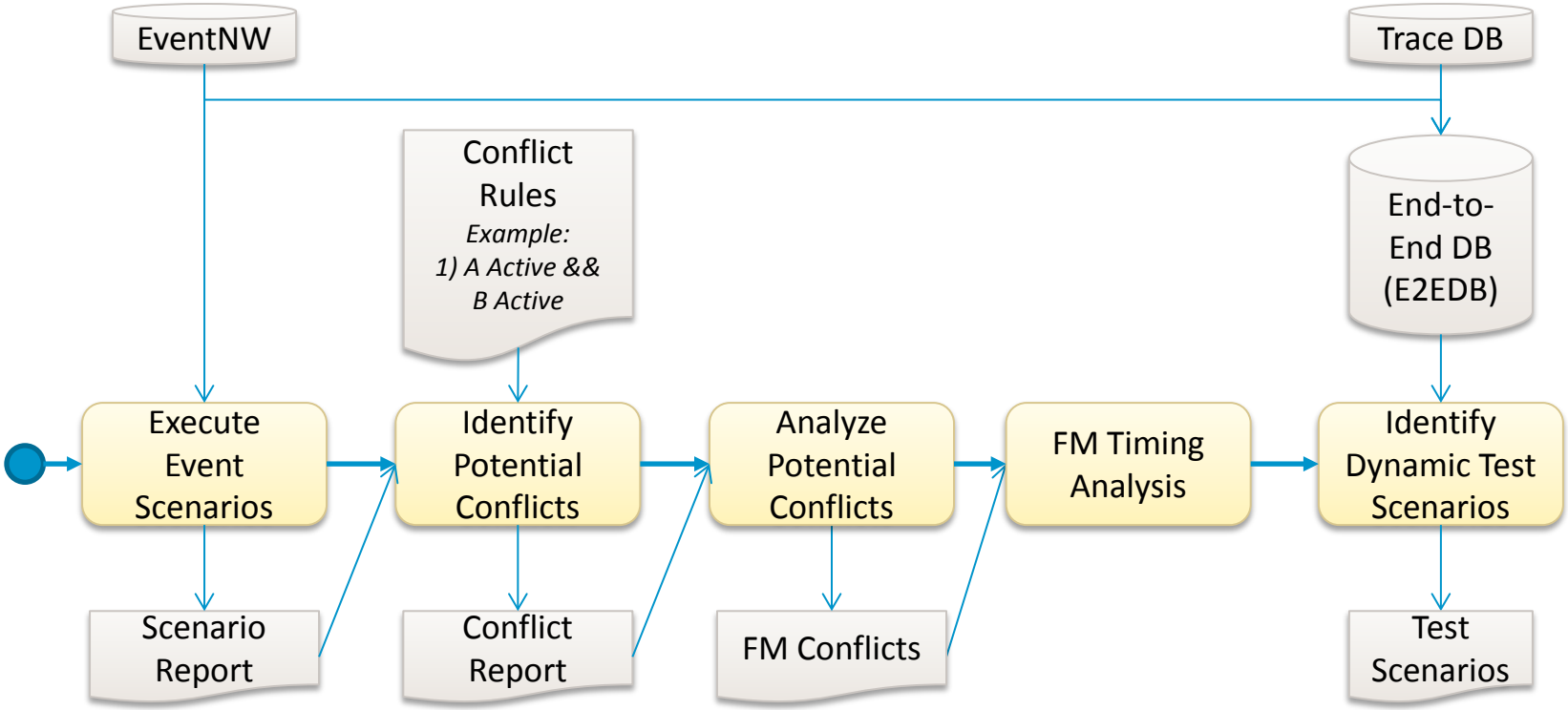
[1] *Clarus Concept of Operations.* Publication No. FHWA-JPO-05-072, Federal Highway Administration (FHWA), 2005

Proposed Approach: System Model Generation Process



FM HW and SC dependency will aid in Change Impact Analysis

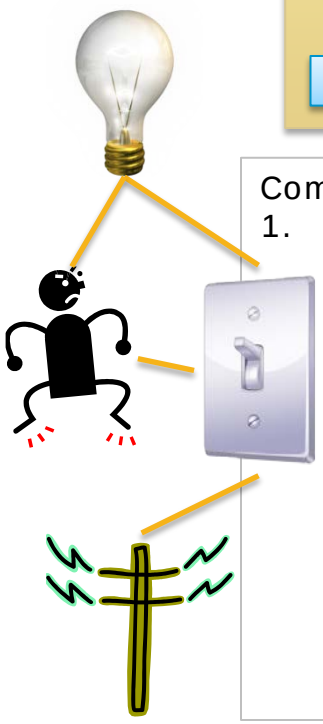
Proposed Approach: Conflict Analysis Process

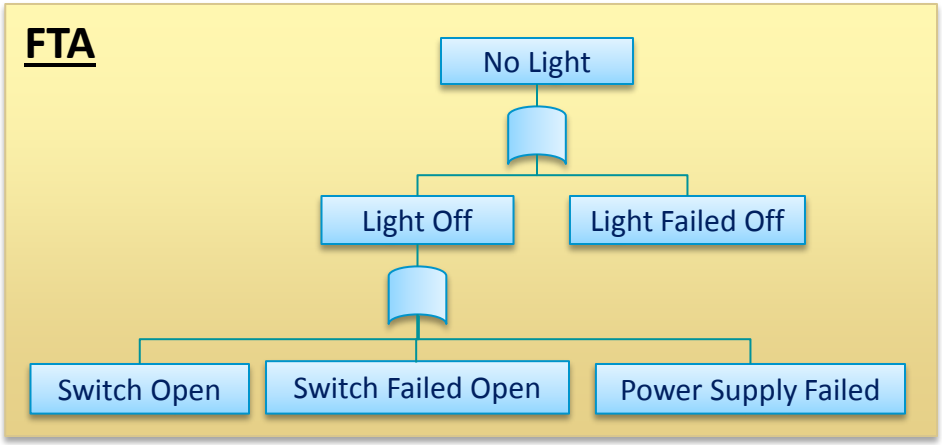


Project Artifact
IV&V Process
IV&V Artifact

Full End-to-End conflict and Change Impact Analysis is possible

Proposed Approach: Example



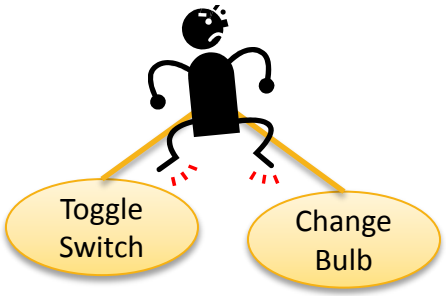


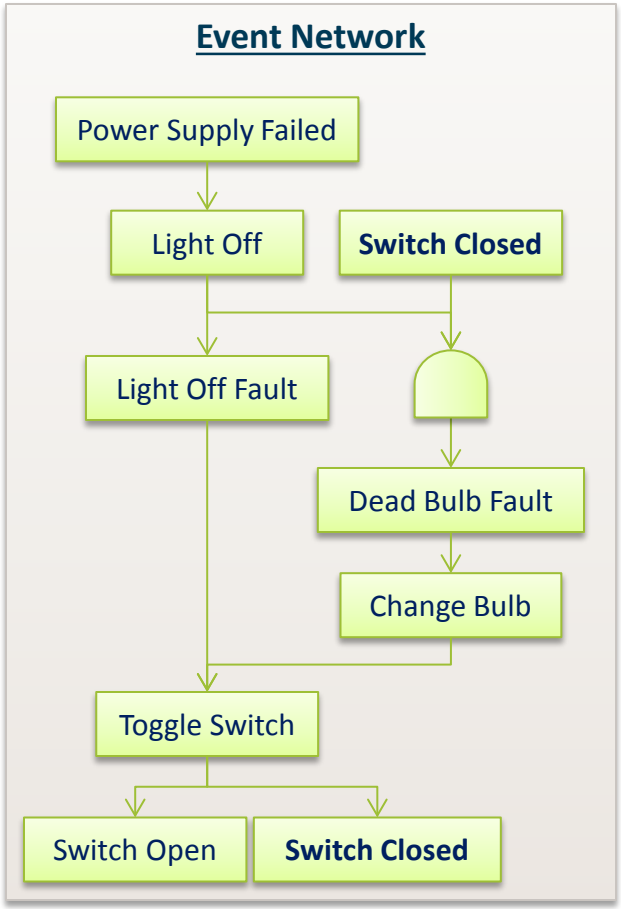
Components/*States*

1. System
   1. Light
      1. *On*
      2. *Off*
      3. *Failed Off*
   2. Switch
      1. *Open*
      2. *Closed*
      3. *Failed Open*
      4. *Failed Closed*
   3. Power Supply
      1. *Nominal*
      2. *Failed*

Conflict Rules:

1) >1 Bulb changed / day





Status and Results

- FM Database (FTA, FMEA) Integrity (i.e. Traceability Analysis) has uncovered severe issues in one portion of the system:
  - Missing Sensor Collection/Processing Requirements – to support FM
  - Missing Fault Requirement / Implementation
  - ~300 lower severity issues impacted developer FM assurance
- SW Lifecycle Traces under active development
  - Mixture of present and past traces through flow/activity diagrams and artifact mapping tables
- First Iteration of Event Modeling of one subsystem
  - Late Lifecycle: Most software behaviors are verified
  - Custom IV&V event network modeling/visualization tools and database design
  - Custom IV&V network parsing and conflict violation highlighting

Future Efforts and Conclusions

- Expand FM Database and Lifecycle Traceability to all subsystems
  - Integrate and automate Change Impact Analysis
- Refine Event Network and Conflict Rules
  - Iterate Event Network and expand to multiple subsystems
  - Build comprehensive set of Conflict Rules and execute tools to identify potential conflict scenarios
- Develop test cases and perform Independent Testing using IV&V test bed
  - Confirm absence of conflicts as well as confirm their presence
- Stretch Efforts:
  - Integrate Portfolio Based Risk Assessments (PBRA) and Risk Based Assessments (RBA) to more clearly define and document the criticality
  - Integrate Assurance Case Goal Structured Network (GSN)
- Conclusions:
  - Early results provided ~300 findings to improve developer (and IV&V) FM Assurance
  - Significant findings with <10% additional effort

Acronyms/Abbreviations

Acronym	Definition
ARD	Algorithm Requirement Document
CMD	Command
DB	Database
FM	Fault Management
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
GSN	Goal Structured Network
IV&V	Independent Verification and Validation
PBRA	Portfolio Based Risk Assessment
Q1	Question 1: Does the system do what its supposed to do
Q2	Question 2: Does the system not do what its not supposed to do
Q3	Question 3: Does the system behave correctly under adverse conditions
RBA	Risk Based Assessment
REQ	Requirement
SC	Stored Command
SW	Software
TLM	Telemetry

References:

NASA Fault Management Handbook Draft 2:

*www.**nasa**.gov/pdf/636372main_**NASA**-HDBK-1002_Draft.pdf*