



Cyber Threat Modeling

Approaches and Tradeoffs

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Threat Modeling and Medical Device Cybersecurity, a National Security Perspective

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Outline

- Introduction
- Cyber Threat Modeling Process and Approaches
- Virtual Testbeds
- ADROC: AAdvancing Resilience Of Control Systems
- Summary and Recommendations



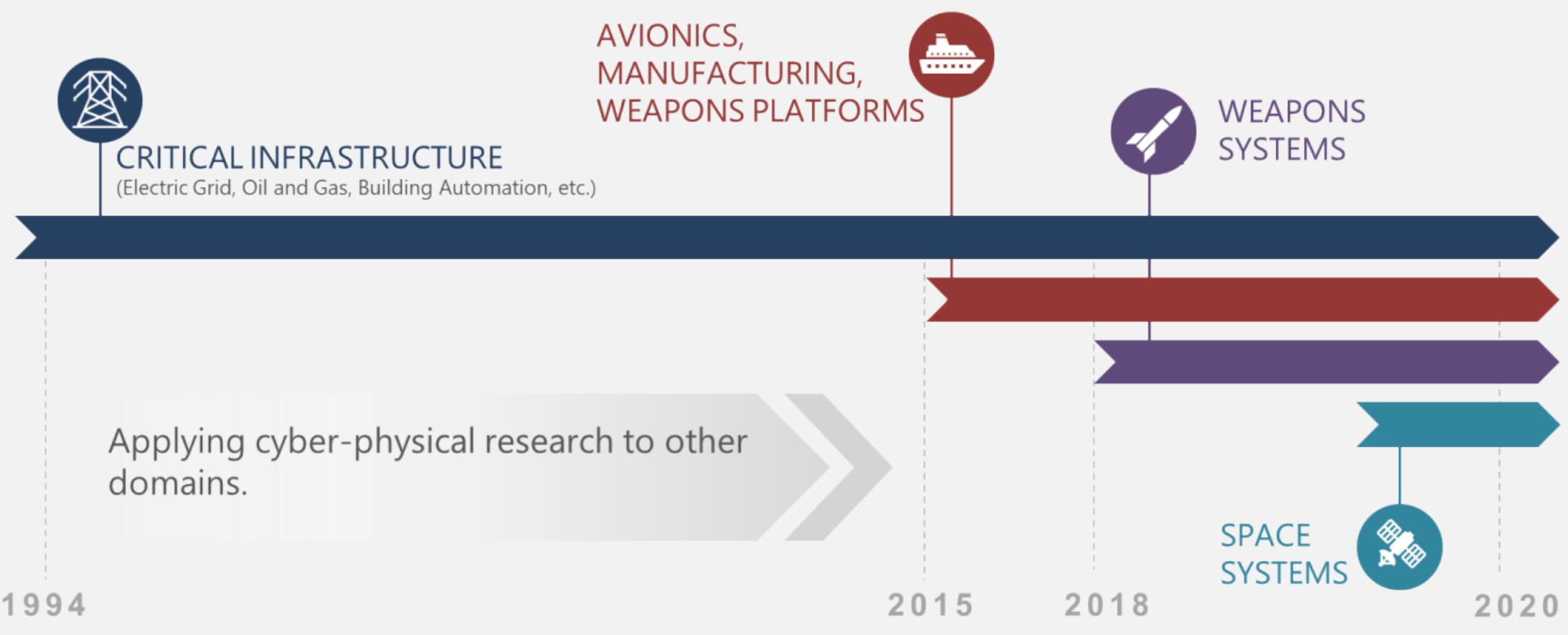
Sandia National Laboratories

- Established in 1949
- Federally funded research and development center
- Managed by National Technology and Engineering Solutions of Sandia for US Department of Energy
- National security mission includes cybersecurity elements



Sandia's Major Program Portfolios

Timeline of Cyber-Physical R&D at Sandia



Modeling and simulation is a core capability of our cyber-physical research at Sandia.

Examples of Cyber-Physical Modeling Activities



Exercises and Training



Situational Awareness & Security



Intrusion Detection



Enhanced Rigor for Cyber Experimentation

Despite the different applications, model development follows a common set of steps.

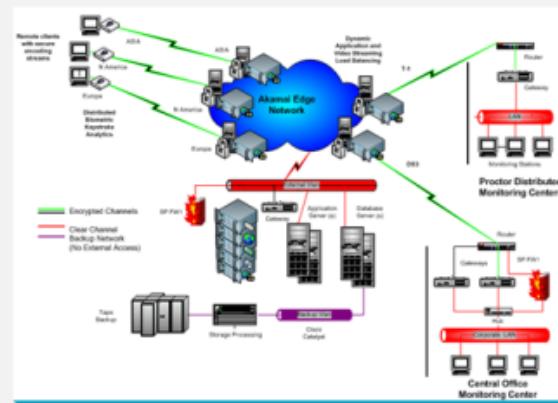
Step 1: ID questions to be addressed



These questions inform many of the modeling decisions modelers have to make

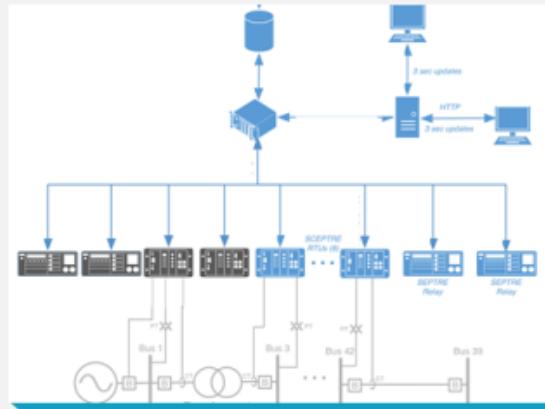
- Scope (elements represented)
- Higher/lower fidelity elements
- Threat-system interactions
- Model outputs

Step 2: Consider possible modeling approaches



ACTUAL SYSTEM

REAL HARDWARE
REAL SOFTWARE



VIRTUALIZED
TESTBED

ABSTRACT HARDWARE
REAL SOFTWARE

$$\begin{aligned} \partial \bar{\theta}^M T(\xi) &= \frac{\partial}{\partial \theta} \int_{\mathbb{R}_n} T(x) f(x, \theta) dx = \int_{\mathbb{R}_n} \frac{\partial}{\partial \theta} T(x) f(x, \theta) dx, \\ \frac{\partial}{\partial a} \ln f_{a, \sigma^2}(\xi_1) &= \frac{(\xi_1 - a)}{\sigma^2} f_{a, \sigma^2}(\xi_1) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\xi_1 - a)^2}{2\sigma^2}}, \\ \int_{\mathbb{R}_n} T(x) \cdot \frac{\partial}{\partial \theta} f(x, \theta) dx &= M \left(T(\xi) \cdot \frac{\partial}{\partial \theta} \ln L(\xi, \theta) \right) \int_{\mathbb{R}_n} T(x) f(x, \theta) dx, \\ \int_{\mathbb{R}_n} T(x) \cdot \left(\frac{\partial}{\partial \theta} \ln L(x, \theta) \right) \cdot f(x, \theta) dx &= \int_{\mathbb{R}_n} T(x) \left(\frac{\partial}{\partial \theta} \ln L(x, \theta) \right) f(x, \theta) dx, \\ \frac{\partial}{\partial \theta} M T(\xi) &= \frac{\partial}{\partial \theta} \int_{\mathbb{R}_n} T(x) f(x, \theta) dx = \int_{\mathbb{R}_n} \frac{\partial}{\partial \theta} T(x) f(x, \theta) dx, \\ 1 &= \exp \left[-\frac{(\xi_1 - a)^2}{2\sigma^2} \right] \cdot \frac{\partial}{\partial a} \ln f_{a, \sigma^2}(\xi_1) \end{aligned}$$

SIMULATION

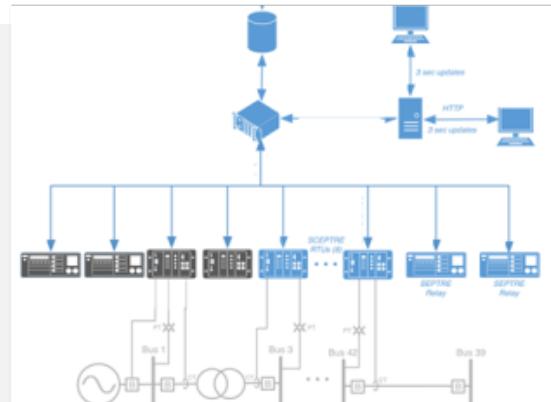
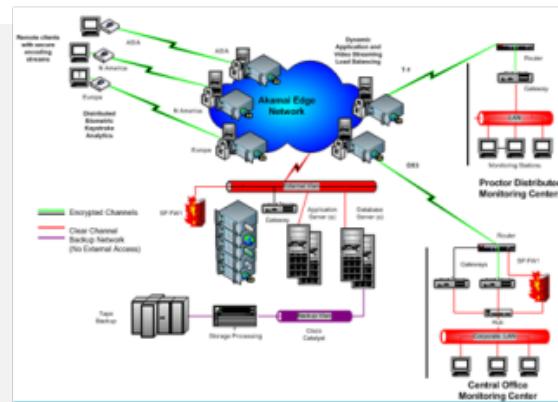
ABSTRACT HARDWARE
ABSTRACT SOFTWARE



"BAD DAY"
BRAINSTORMING

SUBJECT MATTER
EXPERT-DRIVEN

Step 3: Compare approaches vs. needs/constraints



$$\frac{\partial \bar{\theta}}{\partial \theta} M T(\xi) = \frac{\partial}{\partial \theta} \int_{\mathbb{R}_+} T(x) f(x, \theta) dx = \int_{\mathbb{R}_+} \frac{\partial}{\partial \theta} f(x, \theta) dx,$$

$$\frac{\partial}{\partial \alpha} \ln f_{\alpha, \sigma^2}(\xi_1) = \frac{(\xi_1 - \alpha)}{\sigma^2} f_{\alpha, \sigma^2}(\xi_1) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\xi_1 - \alpha)^2}{2\sigma^2}},$$

$$\int_{\mathbb{R}_+} T(x) \cdot \frac{\partial}{\partial \theta} f(x, \theta) dx = M \left(T(\xi) \cdot \frac{\partial}{\partial \theta} \ln L(\xi, \theta) \right) \int_{\mathbb{R}_+} T(x) f(x, \theta) dx,$$

$$\int_{\mathbb{R}_+} T(x) \cdot \left(\frac{\partial}{\partial \theta} \ln L(x, \theta) \right) \cdot f(x, \theta) dx = \int_{\mathbb{R}_+} T(x) \left(\frac{\partial}{\partial \theta} \ln f(x, \theta) \right) f(x, \theta) dx,$$

$$\frac{\partial \bar{\theta}}{\partial \theta} M T(\xi) = \frac{\partial}{\partial \theta} \int_{\mathbb{R}_+} T(x) f(x, \theta) dx = \int_{\mathbb{R}_+} \frac{\partial}{\partial \theta} f(x, \theta) dx,$$

$$1 - \exp \left[- \frac{(\xi_1 - \alpha)^2}{2\sigma^2} \right] \frac{\partial}{\partial \theta} \ln f_{\alpha, \sigma^2}(\xi_1) = \frac{\partial}{\partial \theta} \ln f_{\alpha, \sigma^2}(\xi_1) \cdot \frac{\partial}{\partial \theta} \exp \left[- \frac{(\xi_1 - \alpha)^2}{2\sigma^2} \right].$$



ACTUAL SYSTEM

VIRTUALIZED TESTBED

SIMULATION

“BAD DAY” BRAINSTORMING

Increasing Realism
Decreasing Flexibility
Increasing Cost
Increasing Time

Increasing Abstraction
Increasing Flexibility
Decreasing Cost
Decreasing Time

Technical requirements vary across approaches, but need for system and threat SMEs is common.

Virtual Testbeds, i.e., Emulation

- Often provides balance of realism and flexibility
- Can consist of
 - Virtual machines
 - Real software, operating systems, communication protocols
 - Can connect with simulation of physical (or biological) process
 - Can include hardware-in-the-loop (if needed)
 - Threat vector (real or emulated)
- Provides safe environment for threat investigation
 - Realistic threats (e.g., actual malware) or actual attacks
 - Won't cause actual damage
 - Can observe effects of attack
 - Spin up/tear down environment as needed

SCEPTRE: Emulation of Cyber-Physical Systems

phēnix
Sandia's phēnix orchestration tool allows users to quickly deploy, undeploy, and interact with SCEPTRE ICS environments

SCADA Applications
▪ Industry standard software for SCADA applications, including:

- Human Machine Interfaces (HMI)
- OPC and SCADA servers
- Database historians

Software Defined Networking
▪ ICS devices (simulated, emulated, real) communicate and interact via high fidelity SCADA protocols

- ModbusTCP, DNP3, IEC 61850 and 60870
- Written to specification
- Enabling technology that allows communication between Hardware-in-the-Loop (HITL) and simulated devices

SCEPTRE ICS Field Devices
▪ Simulated ICS devices

- RTUs, PLCs, protection relays, FEPs
- Communicate using high fidelity, to spec SCADA protocols

- Emulated PLCs
- HITL devices such as relays, PLCs, RTUs

End Process Simulation
▪ SCEPTRE integrates field devices and end process simulations to provide realistic responses in the physical process as events occur in the control system and vice versa

- Leverage industry standard software to provide realistic end process models

Threat Modeling
Execute live attacks within the SCEPTRE SCADA environment

Real Time SCADA Analysis
Continuously collect data for test and evaluation, design, and analytics

Consequence Modeling
Frequency vs. Time

Map of the Western United States showing regions colored by frequency (Hz):

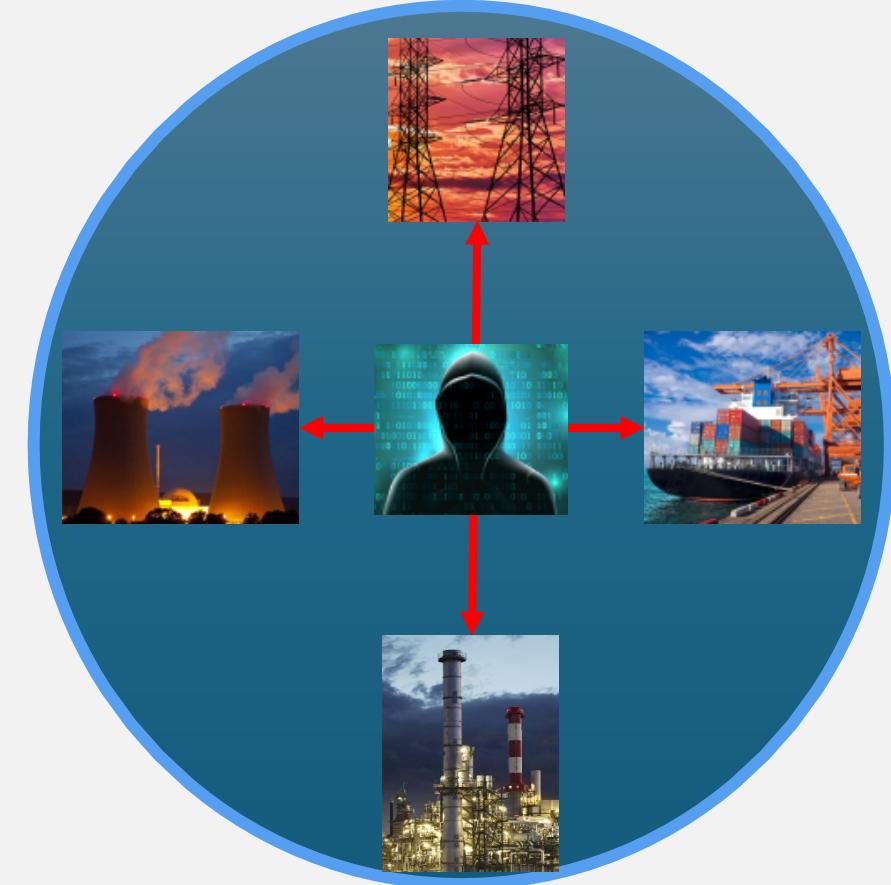
- Kemano
- Coulee
- The Dalles
- Midpoint
- Northwest
- Jim Bridger
- Tesla
- Central
- Valley
- Mona
- Auli
- Moenkopi
- Four Corners

Use Cases

- Training and exercise support
- Mission rehearsal
- Test and evaluation
- Analysis: vulnerabilities, criticality, dependencies, malware sandbox
- Challenges
 - Operates in real-time which can be time-limiting
 - Significant learning curve
 - Heterogeneity of devices may present challenges
 - Validation of results?

ADROC: AAdvancing Resilience Of Control Systems

- New research effort
- **Goal:** develop cyber experimentation platform for quantitative analysis and characterization of threats to industrial control systems (ICS)
- **Approach:** mathematical and emulation modeling



ADROC Project

INPUTS: Threats

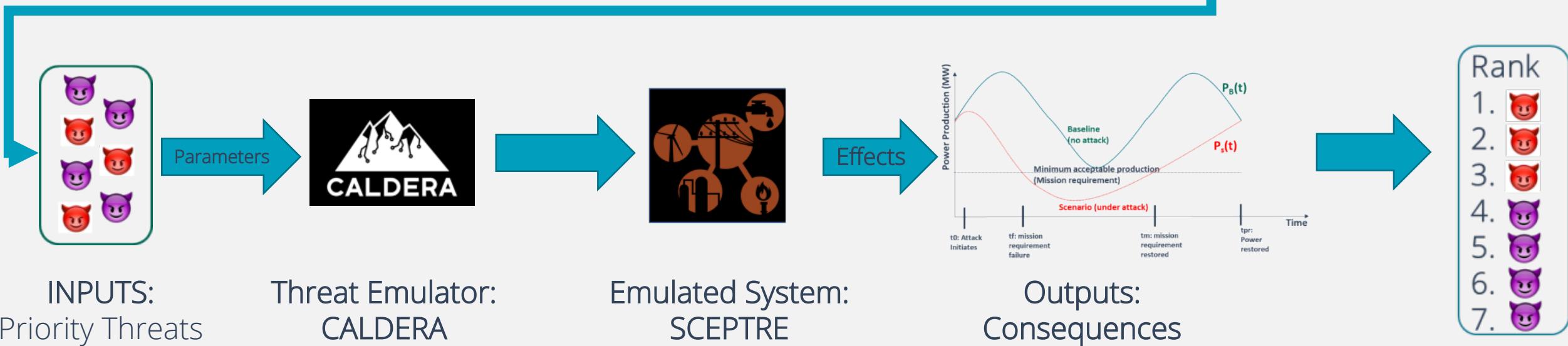
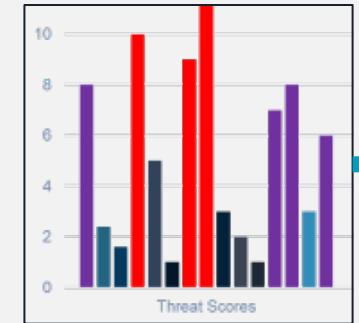


Parameters

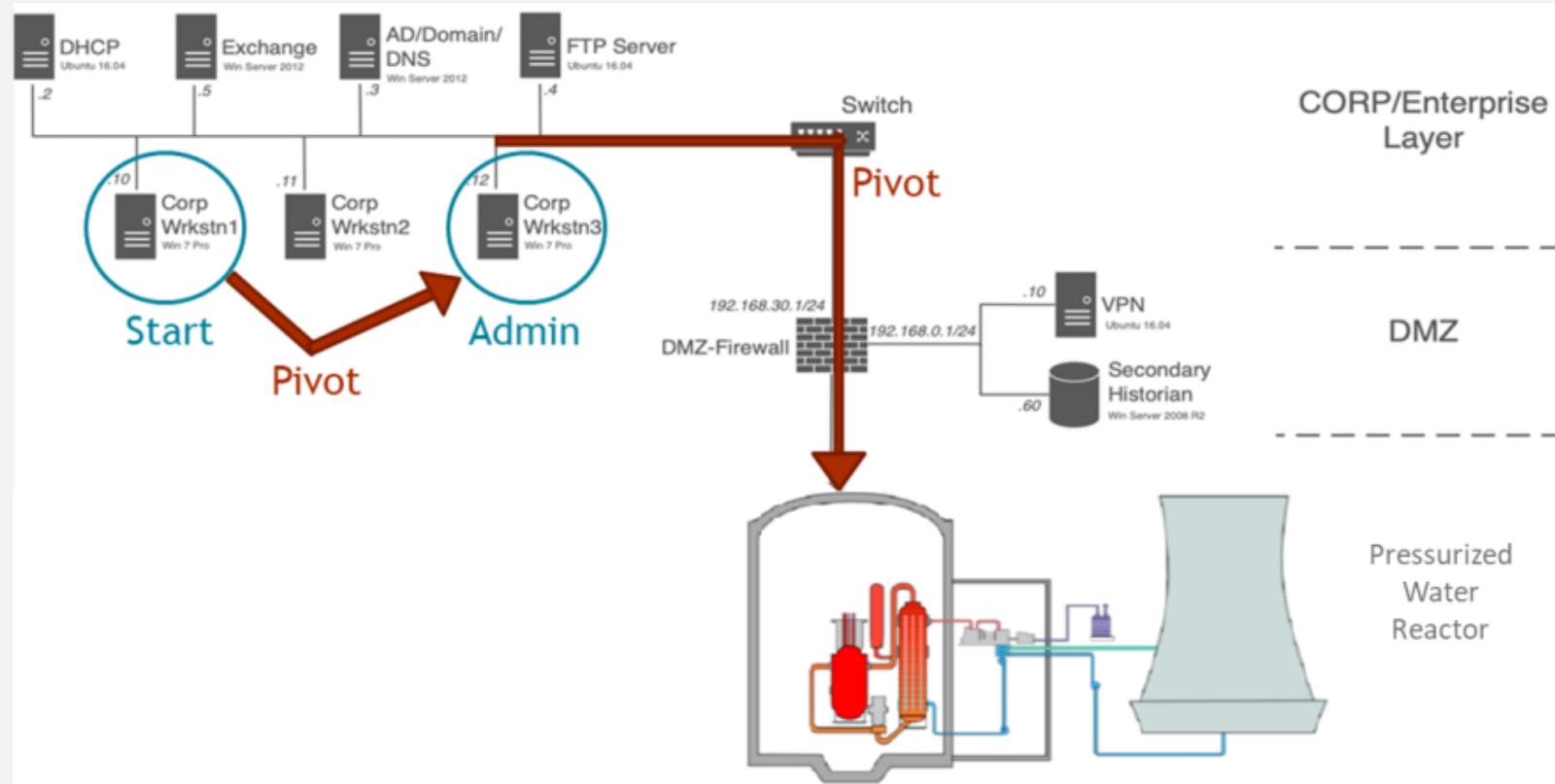
Math
Models

Data

Outputs: Scores

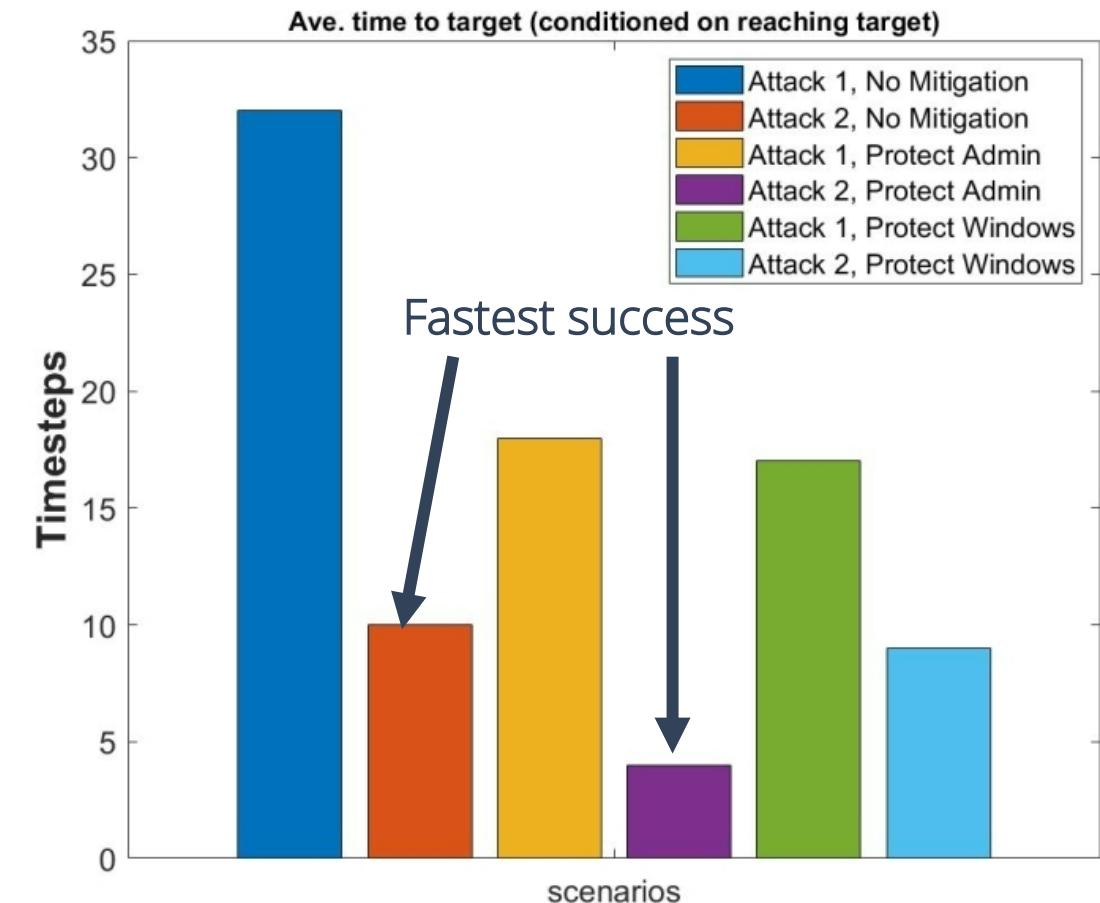
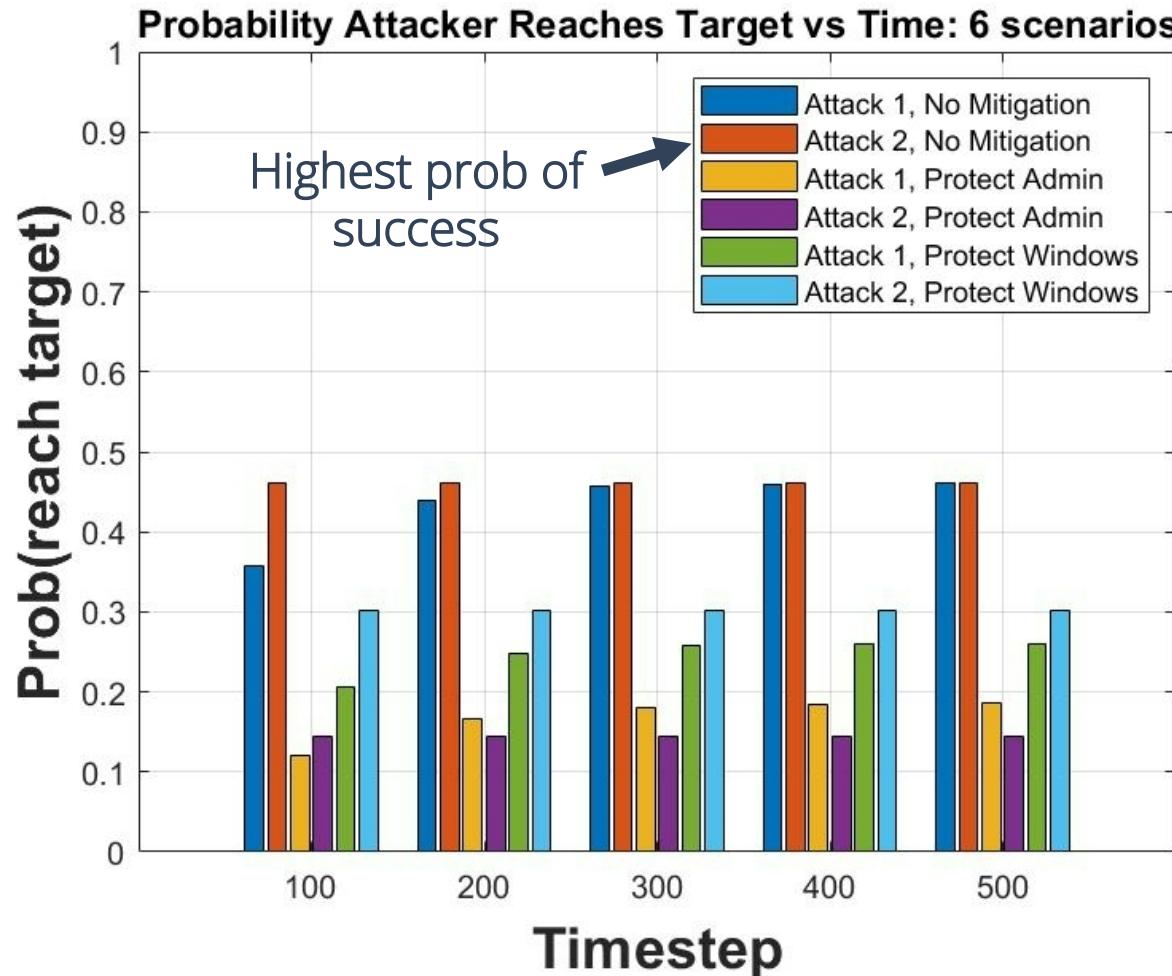


Scenario: Attack on Nuclear Power Plant



Attacker goal: cause unsafe conditions

Math Modeling: Example Results

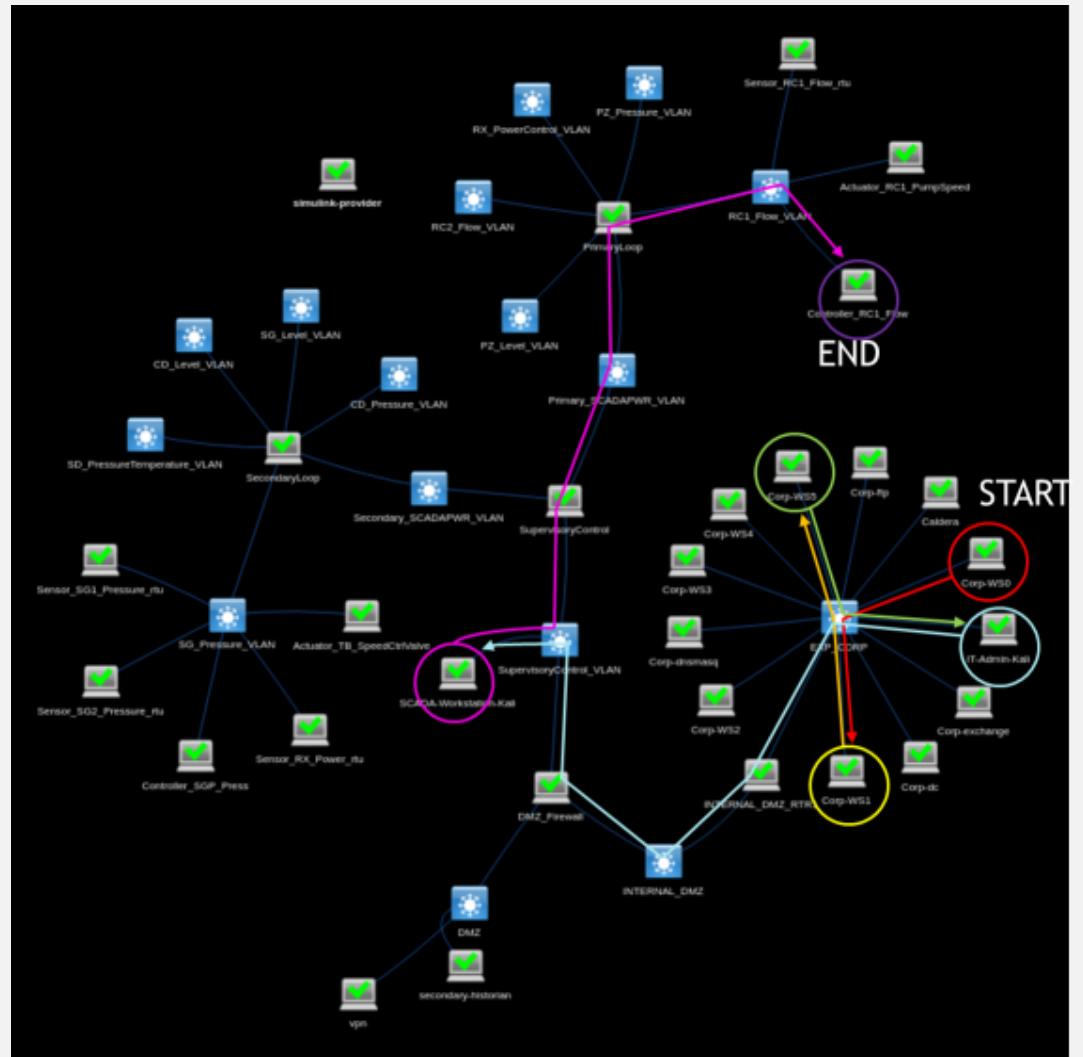


Limitation: fast but can't determine impact of attack

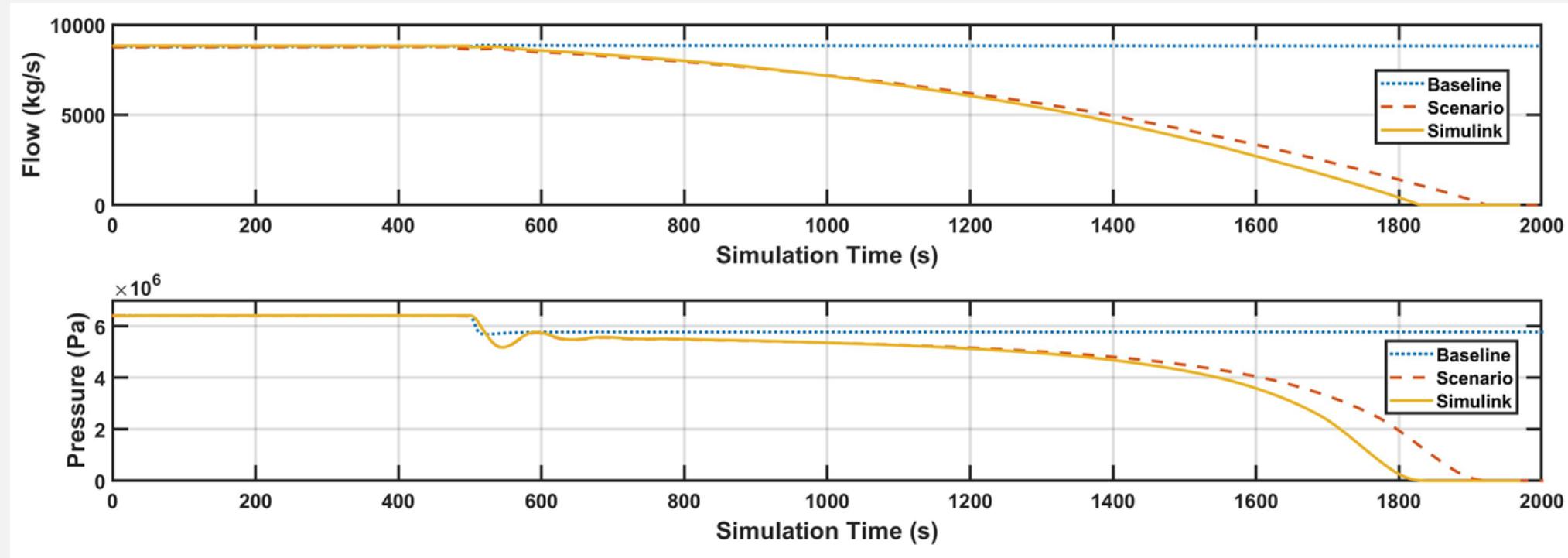
Emulation Modeling: Example Results

Emulation allows us to

- Track movement of malware
- Observe targeted device
- Quantify effect of attack



Emulation Modeling: Example Results



Attack destabilizes pressure and flow

*Figures from Hahn, et al., "Automated Cyber Security Testing Platform for Industrial Control Systems," 12th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, 2021.

Summary

- Several approaches exist for modeling cyber threats
- Virtual testbeds (emulation) are an emerging technology that provides a “safe” environment for cyber threat investigation
- The ADROC project is using a hybrid modeling approach to enable efficient AND “validate-able” prioritization of threats

Recommendations

Before building a model

- Formally state the question you are trying to answer
- Develop a conceptual model of the system and threat
- Evaluate your needs and constraints (time, budget, capabilities)

Remember

- There is no single, perfect method
- Your answers will only be as good as your data permits
- Start slowly and eventually build in complexity

Thank you

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