Systems Thinking and Model Based Systems Engineering's Utility to Solve Complex Organizational Problems - Cyber-Physical System Design Teams

Martin "Trae" Span, Shwetha Gowdanakatte, **Jeremy Daily**, Indrakshi Ray, Kamran Eftekhari Shahroudi

Colorado State University

Fort Collins, CO, USA

Summary

- Demonstrate the Utility of Systems Thinking and MBSE

  Using causal loop and SysML block definition diagrams
- Perform systematic identification of security shortcomings of cyber-physical system (CPS) design teams
- Propose and defend potential solutions

Overview

Motivation

Background Work

Characterization of the Problem Space using Systems Thinking Models

Illustration of Solutions Using Systems Thinking Models with CPS Design Teams

Conclusion and Future Work

References

Motivation

Username : admin
Password : admin

The cybersecurity program you
want to run

The cybersecurity program you're
forced to run on your current budget

RANSOMWARE ATTACK

YOUR FILES ARE ENCRYPTED

Background Work

Systems Thinking Foundations:
- Peter Senge *Fifth Discipline* [13]
- Donnella Meadows *Thinking in Systems: A Primer* [9]

INCOSE Body of Knowledge

MBSE applied to various applications
- Autonomous driving [15]
- Aircraft maintenance systems [5]
- Design and development of Internet Of Things (IOT) in smart city applications [6]

Content from Colorado State University Systems Thinking Course [14]
- Key Systems Thinking Principles
  - Emergent Properties of systems – **Failure of reductionist approach to complex system design**

Characterization of the Problem Space

- Current problems with CPS Design Teams:
  - Lack of systems thinking mindset
  - Minimal adoption of systems thinking principles:
    - Holism: Lack of holistic view of a CPS
    - Evolution: Attackers evolve, but CPS does not
    - Emergence: Security is an emergent property, reductionist approach inadequate
    - Feedback: Vulnerabilities emerge from feedback loops and delays

Events
Increasing cyber attacks against CPS Systems

Patterns Of Behavior

Systems Structure

Mental Model
Design team focused only on functionality, cost and schedule

Security is an afterthought and IT's responsibility

CPS Members Lack Cybersecurity Awareness

Characterization of the Problem Space using Systems Thinking Models: CPS Design Team
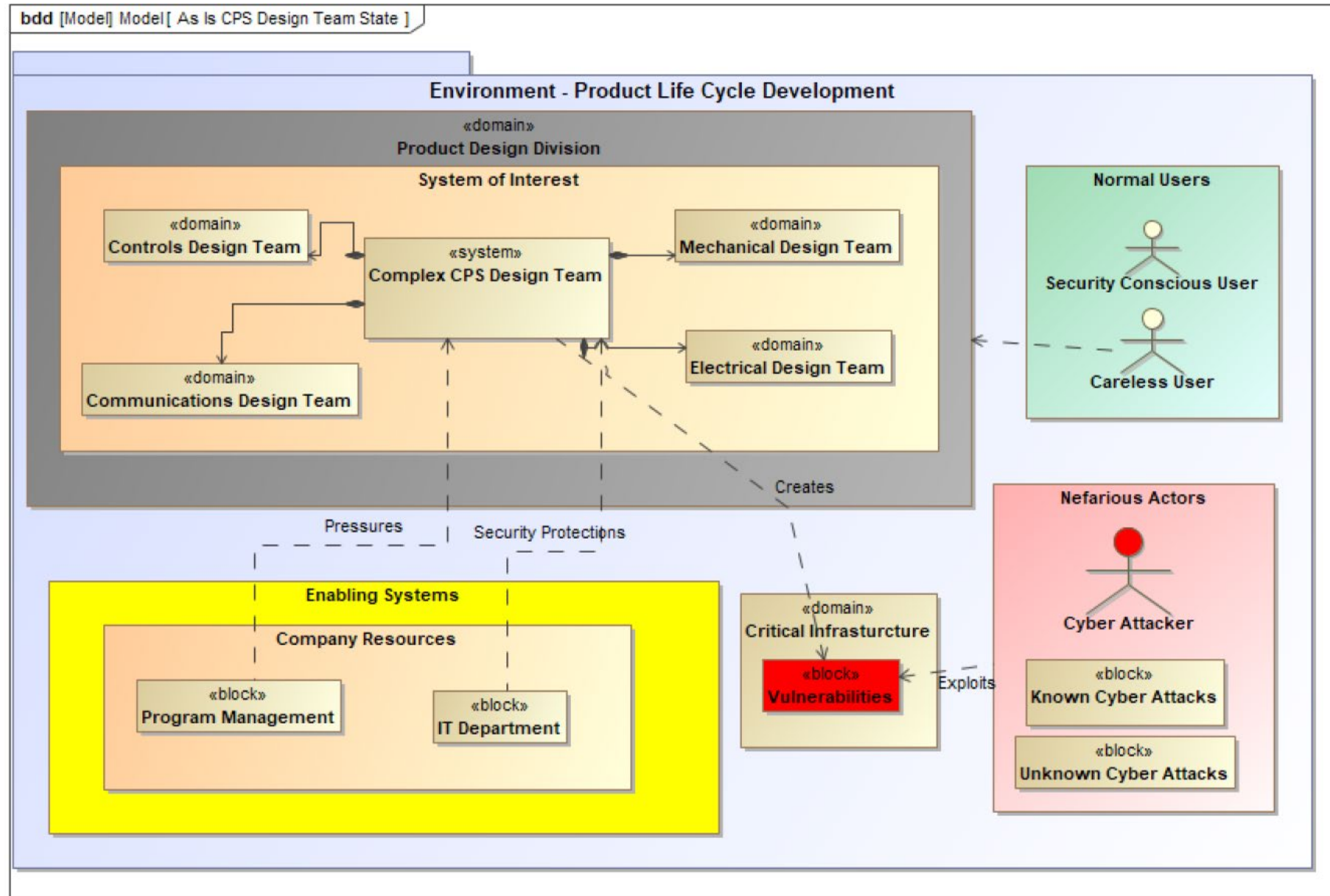

Figure 2: Systemic Identification: SysML Block Definition Diagram (BDD) Modeling CPS Current State

CPS Design Team Current State Systems Dynamics Model

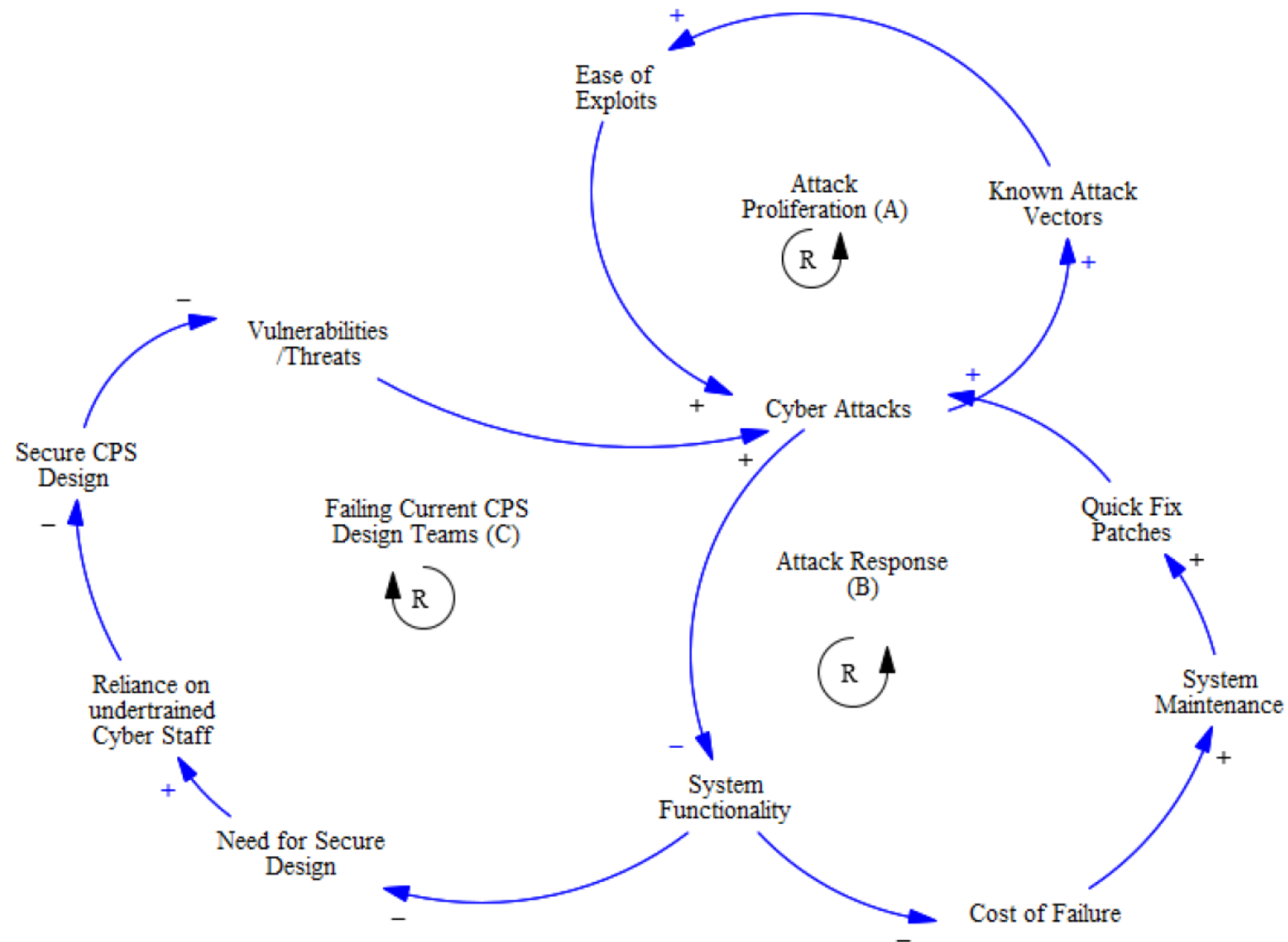Figure 3: Systemic Identification: Causal Loop Diagram showing complexity of CPS Design Team and CPS Security

Diagram generated with VENSIM software

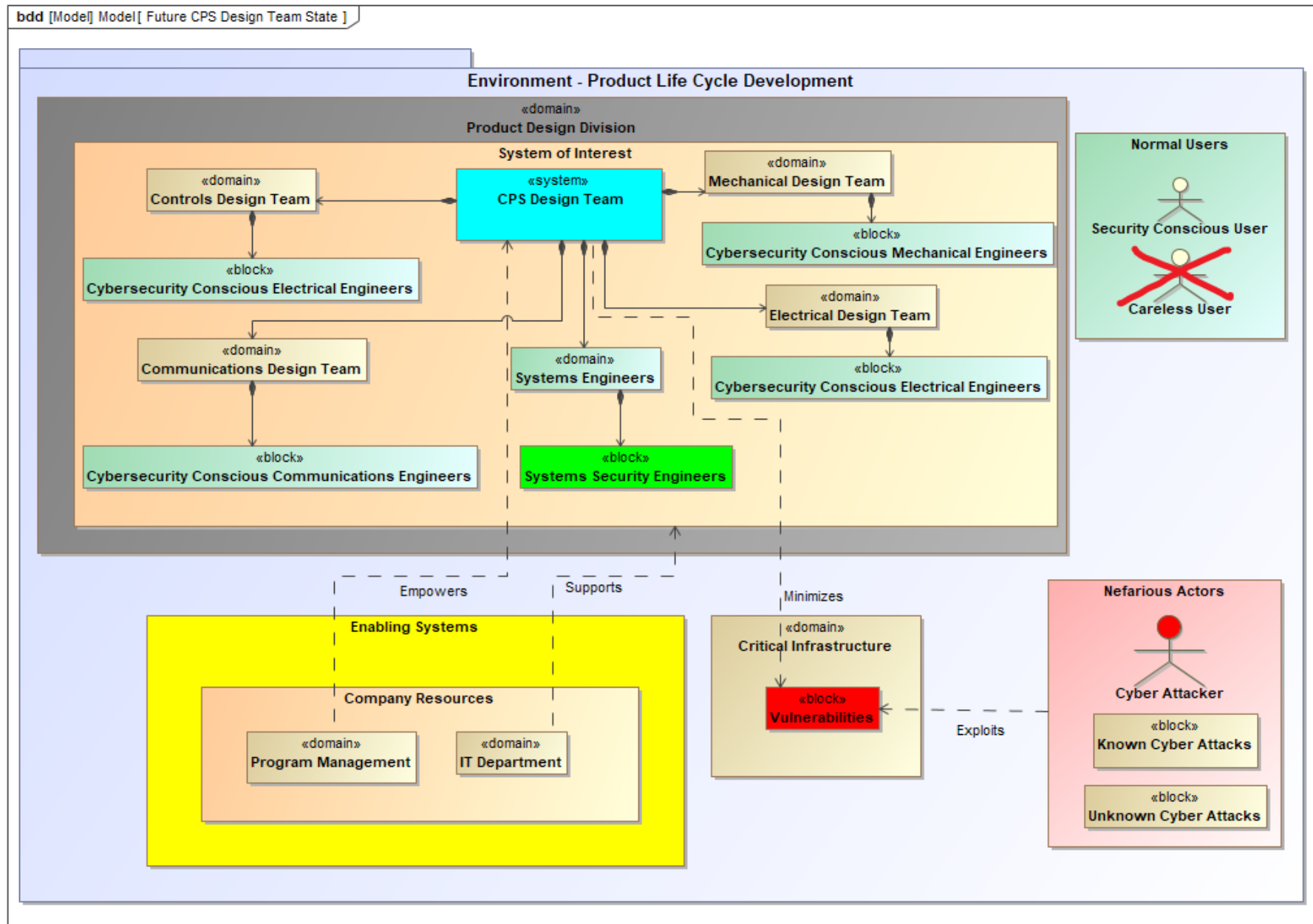# Proposed BDD for more effective CPS Design Team

Figure 4: SysML BDD Of Proposed Design Team Solution

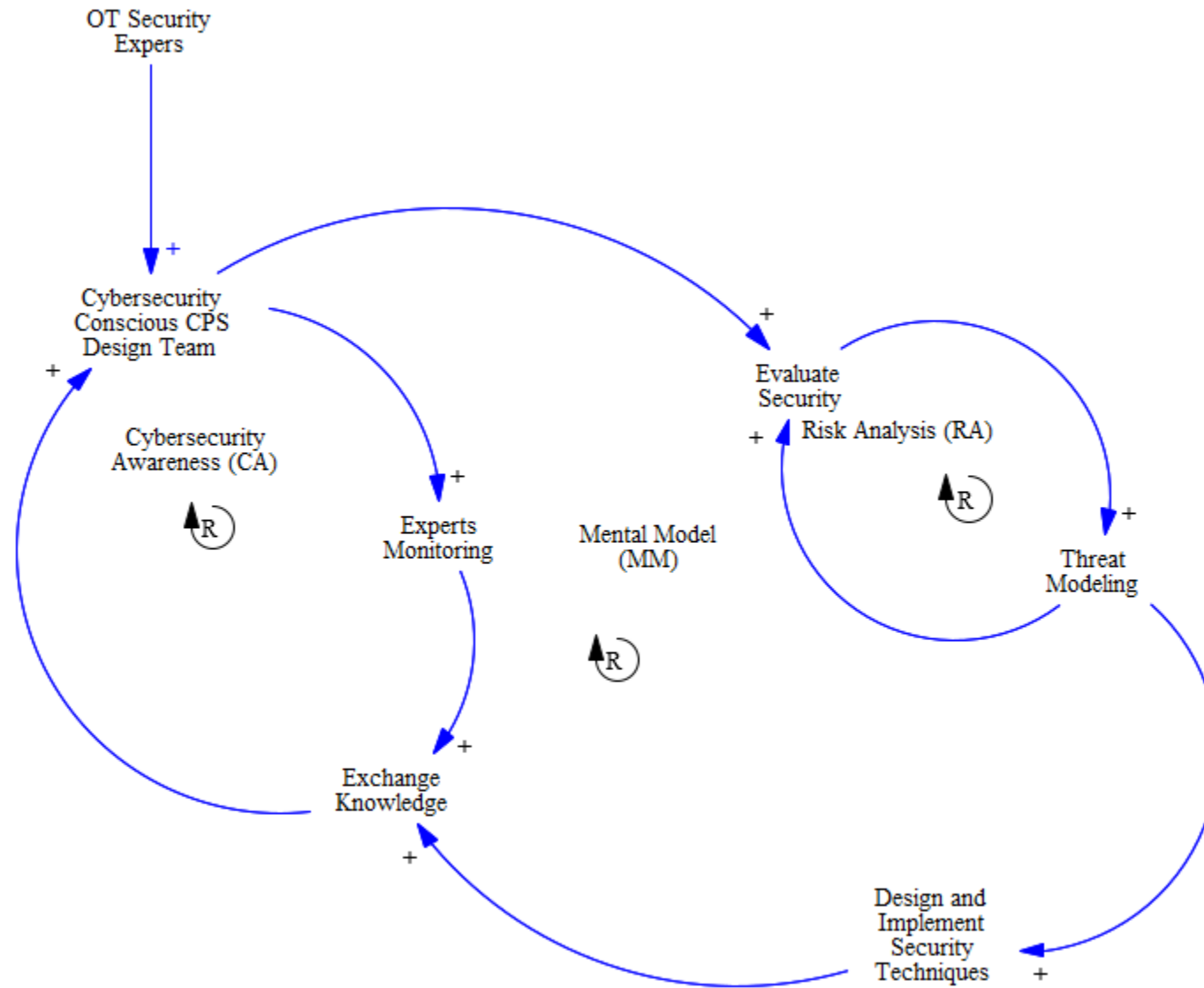# Application of Systems Thinking Models for CPS Design Team

Figure 5: Causal Loops For Secured CPS Design Through Cybersecurity Conscious CPS Design Team

Application of Systems Thinking Models for CPS Design Team
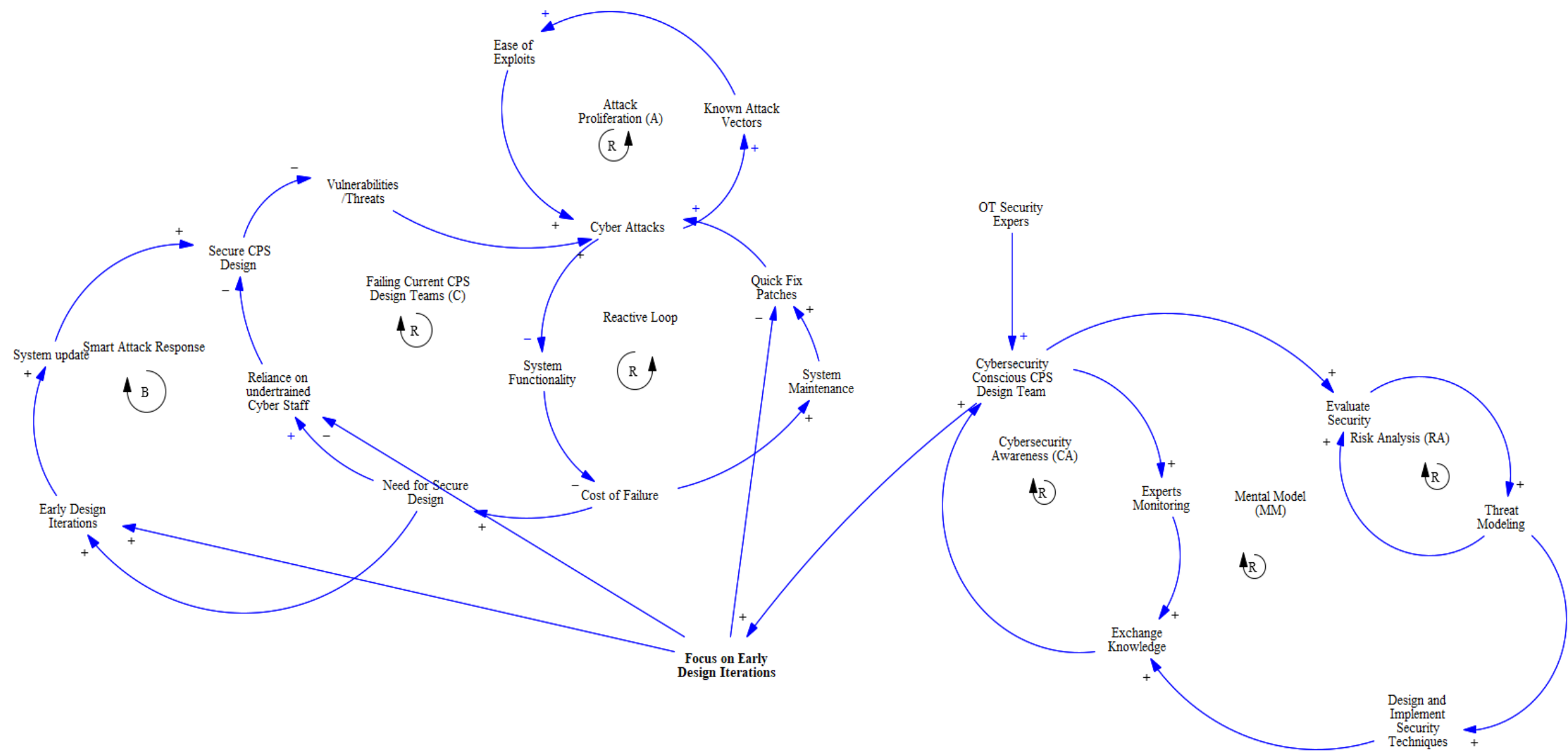
Figure 6: Integration of solution with the problem CLD

Application of Systems Thinking Models for CPS Design Team: Discovery of Unknowns

Events

Emergent Behaviors

The Design Team is focused on CPS design and relies on IT for security

The design team has little to no knowledge of CPS vulnerabilities and possible threats

Proposed Actions

Hire Systems Security Engineering (SSE) and Operational Technology (OT) experts to train the CPS Design team to become cyber-conscious and implement security by design
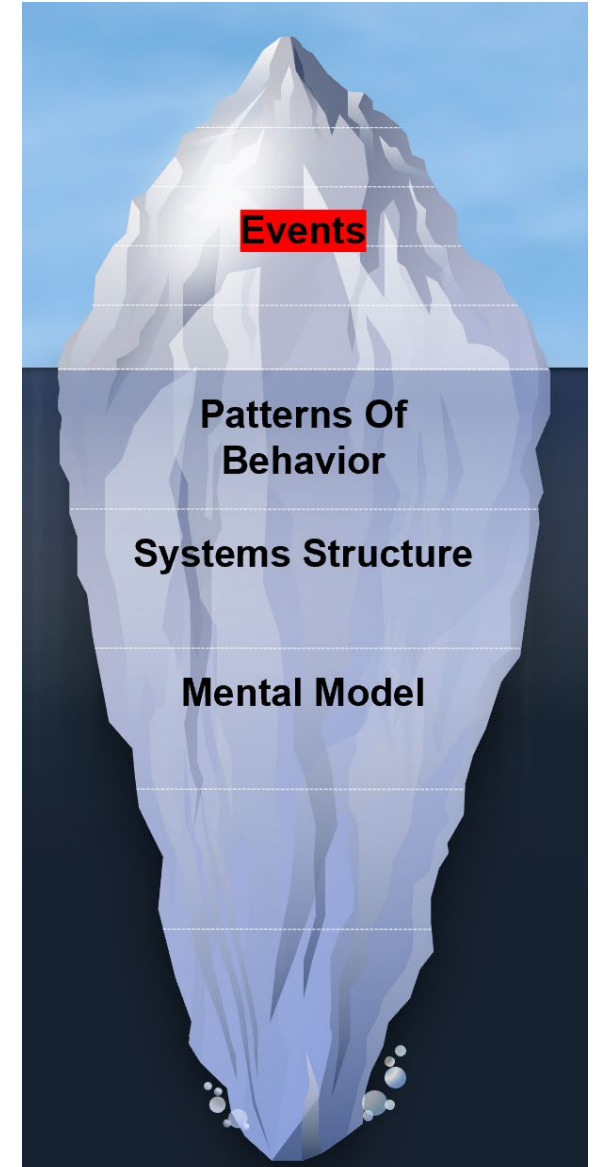
Application of Systems Thinking Models for CPS Design Team: Discovery of Unknowns

Patterns

Emergent Behaviors

*Resistance to change and reluctance to learn new concepts (outside their domain) and new tools design engineers leaving the organization*

Proposed Actions

The organization should inform their teams of recent cyberattacks and their consequences for CPSs

A visual framework may assist in helping the design team understand their significance in securing CPS design, with how and where they fit
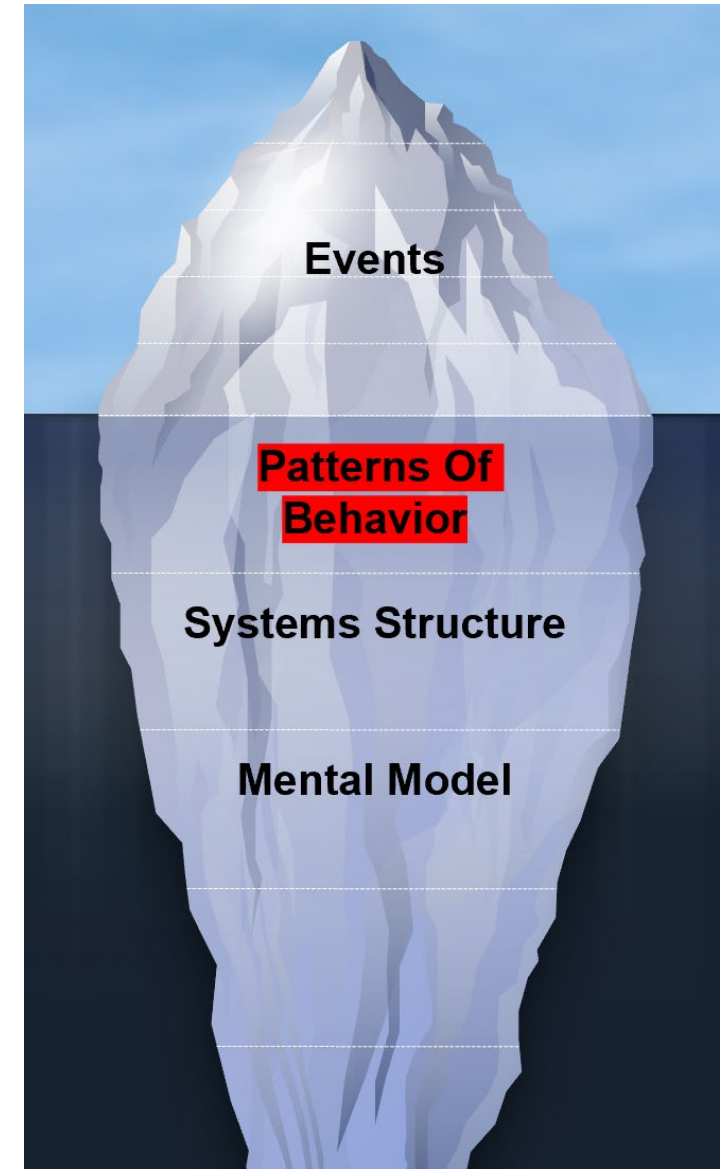
Application of Systems Thinking Models for CPS Design Team: Discovery of Unknowns

Structure

Emergent Behaviors

The CPS design team is an expert in the design and development of CPS, but not in security. IT support for security enabling systems is limited and the environment is driving pressure focused on cost and schedule

Proposed Actions

Train CPS design team on cybersecurity, detection of vulnerabilities, threat modeling, and risk analysis

Promote knowledge sharing through structured mentoring programs, webinars, and seminars on real-world attacks and consequences

Understand system stakeholder incentives and consequences for cybersecurity breaches
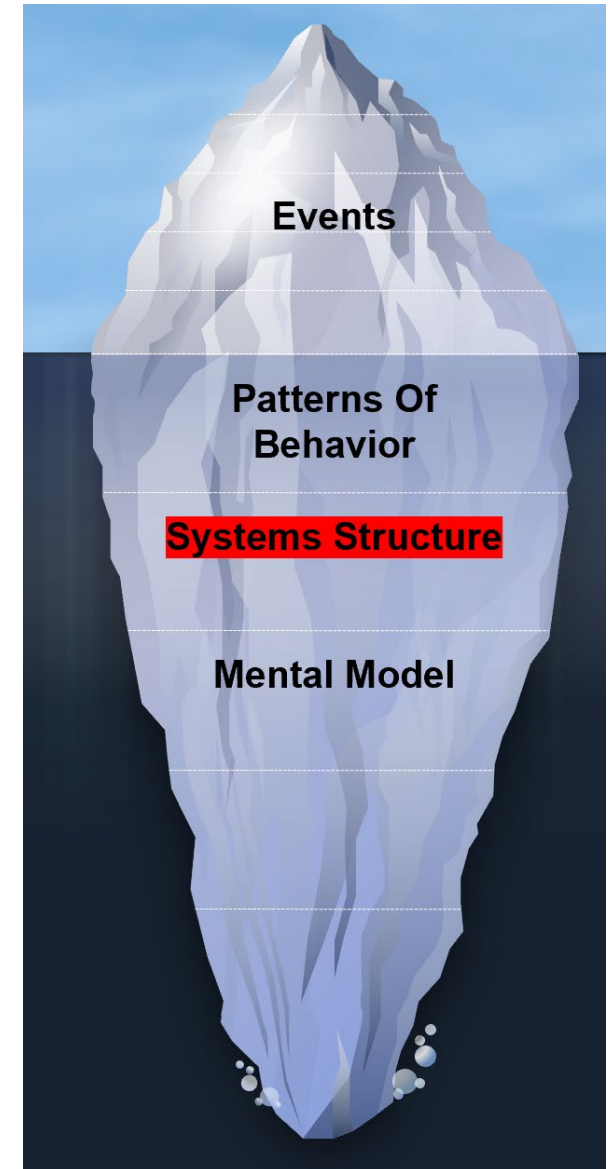
Application of Systems Thinking Models for CPS Design Team: Discovery of Unknowns

Mental Model

Emergent Behaviors

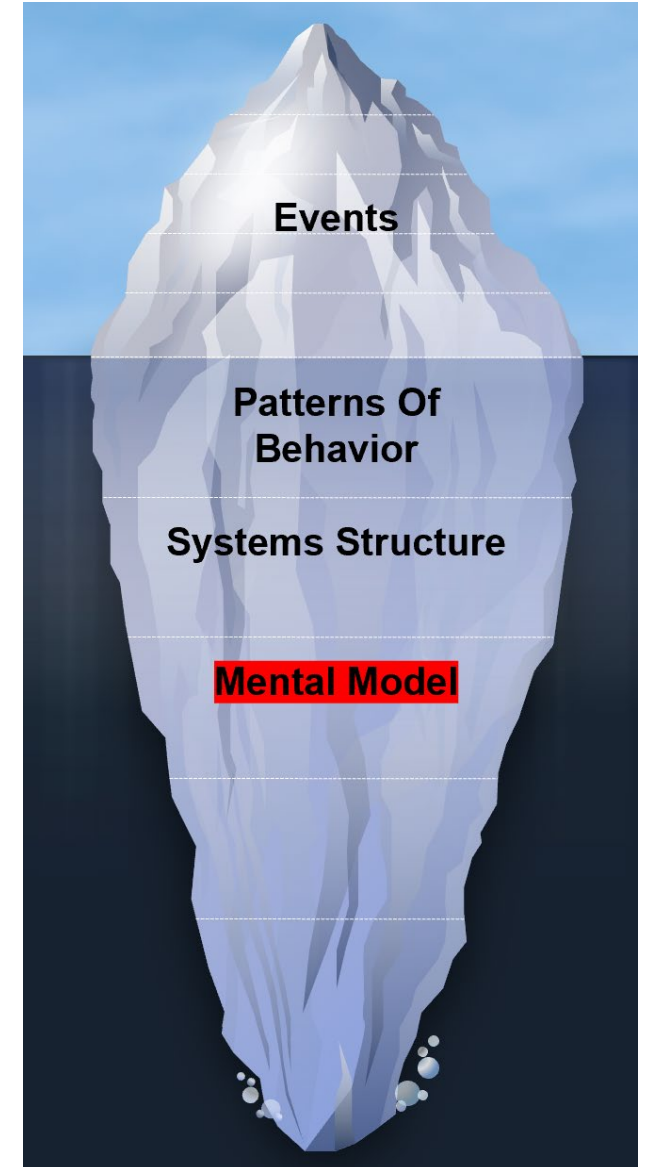*The CPS design team is valued for its expertise in efficient CPS development within cost and schedule*

Security is outside the area of responsibility

Proposed Actions

The gradual transition of the current mindset to adopt security by design

Implement stakeholders' encouragement programs. Conduct surveys to evaluate all stakeholders' feedback

The CyberTruck Challenge Example

https://www.cybertruckchallenge.org/

Conclusion and Future Work

This work illustrates the utility of Systems Thinking and MBSE in solving complex organizational problems.

Using Systems Thinking principles, iceberg models, block definition diagrams, and causal loop diagrams we present an analysis of current CPS design teams systematically identifying the underlying causes of weak security design.

The proposed solution presented in this work for CPS Design teams would help organizations implement Systems Thinking and Systems Security Engineering training to achieve 'Security by Design' for their complex CPS development.

While this work does not present a case study of a solution as implemented in an actual CPS System Design Team, it provides the necessary foundational modeling to justify proposed changes to an organization seeking improvement.

Systems Modeling, specifically the CLD's in this work, provides a low-cost method of demonstrating the value of investing in Systems Thinking and Systems Security Engineering training and new hires required prior to investing significant time and monetary resources in its implementation.

Future work should create an executable CLD and ideally document an attempt to implement this solution in an organization to report its successes and challenges.

References

[1] Weapon systems cybersecurity. Report to Congressional Committees, 2021.

[2] E.N. Ceesay, K. Myers, and P.A. Watters. Human-centered strategies for cyber-physical systems security. ICST Transactions on Security and Safety, 4:154773, 05 2018.

[3] Stephen Checkoway, Damon McCoy, Brian Kantor, Danny Anderson, Hovav Shacham, Stefan Savage, Karl Koscher, Alexei Czeskis, Franziska Roesner, and Tadayoshi Kohno. Comprehensive experimental analyses of automotive attack surfaces. page 6, 2011.

[4] T. M. Chen and S. Abu-Nimeh. Lessons from Stuxnet. Computer, 44(4):91–93, 2011.

[5] Fatine Elakramine, Raed Jaradat, Niamat Ullah Ibne Hossain, Marc Banghart, Chad Kerr, and Safae El Amrani. Applying systems modeling language in an aviation maintenance system. IEEE Transactions on Engineering Management, pages 1–13, 2021.

[6] Matthew Hause, James Hummell, and Fabrice Grelier. Mbse driven iot for smarter cities. In 2018 13th Annual Conference on System of Systems Engineering (SoSE), pages 365–371, 2018.

[7] INCOSE. MBSE Initiative. 2022.

[8] Raymond K. Jonkers and Kamran Eftekhari Shahroudi. A design change, knowledge, and project management flight simulator for product and project success. IEEE Systems Journal, 15(1):1130–1139, 2021.

[9] Donella H Meadows. Thinking in systems: A primer. chelsea green publishing, 2008.

[10] Jamie P Monat and Thomas F Gannon. What is systems thinking? a review of selected literature plus recommendations. American Journal of Systems Science, 4(1):11–26, 2015.

[11] Morteza Nagahi, Niamat Ullah Ibne Hossain, Raed Jaradat, and Siobhan Grogan. Moderation effect of managerial experience on the level of systems-thinking skills. pages 1–5, 2019.

[12] A Pyster, D Olwell, N Hutchison, S Enck, J Anthony, D Henry, and A Squires. Guide to the Systems Engineering Body of Knowledge (SEBoK) version1.0. Hoboken, NJ: The Trustees of the Stevens Institute of Technology, 2012.

[13] Peter Senge. Fifth Discipline: The Art and Practice of the Learning Organization. Random House Books, USA, 2006.

[14] Kamran Shahroudi. Systems Thinking for Real World Applications. 2022.

[15] Henri Sohier, Sahar Guermazi, Mouadh Yagoubi, Pascal Lamothe, Aldo Maddaloni, Pascal Menegazzi, and Yining Huang. A tooled methodology for the system architect's needs in simulation with autonomous driving application. pages 1–8, 2019

Questions?

Contact:

Trae Span   Trae.span@colostate.edu

Jeremy Daily   Jeremy.daily@colostate.edu