Securing the Digital Ecosystem: Designing a CPS Framework for Cyber-Threat Detection for Sustainable Chemical Processes and Operations

By: Zoha Tariq

Priority Topic Area: **Digitalisation, including Cybersecurity**

Introduction

Chemical processes involve the use of complex systems and technologies to produce various chemicals and materials used in everyday life.

Automation and digitalization have become integral to optimizing efficiency, productivity, and safety in chemical engineering processes. However, they also introduce cybersecurity risks, such as malware, ransomware, phishing attacks, insider threats, and nation-state-sponsored cyber espionage. These threats can disrupt operations, compromise safety systems, equipment damage, and cause environmental and economic damage.

This research aims to provide an overview of the connectivity of cybersecurity and the chemical industry and proposes formulation of Cyber-Physical Systems (CPS) consisting of control models and strategies to tackle these cyber threats for more sustainable operations.

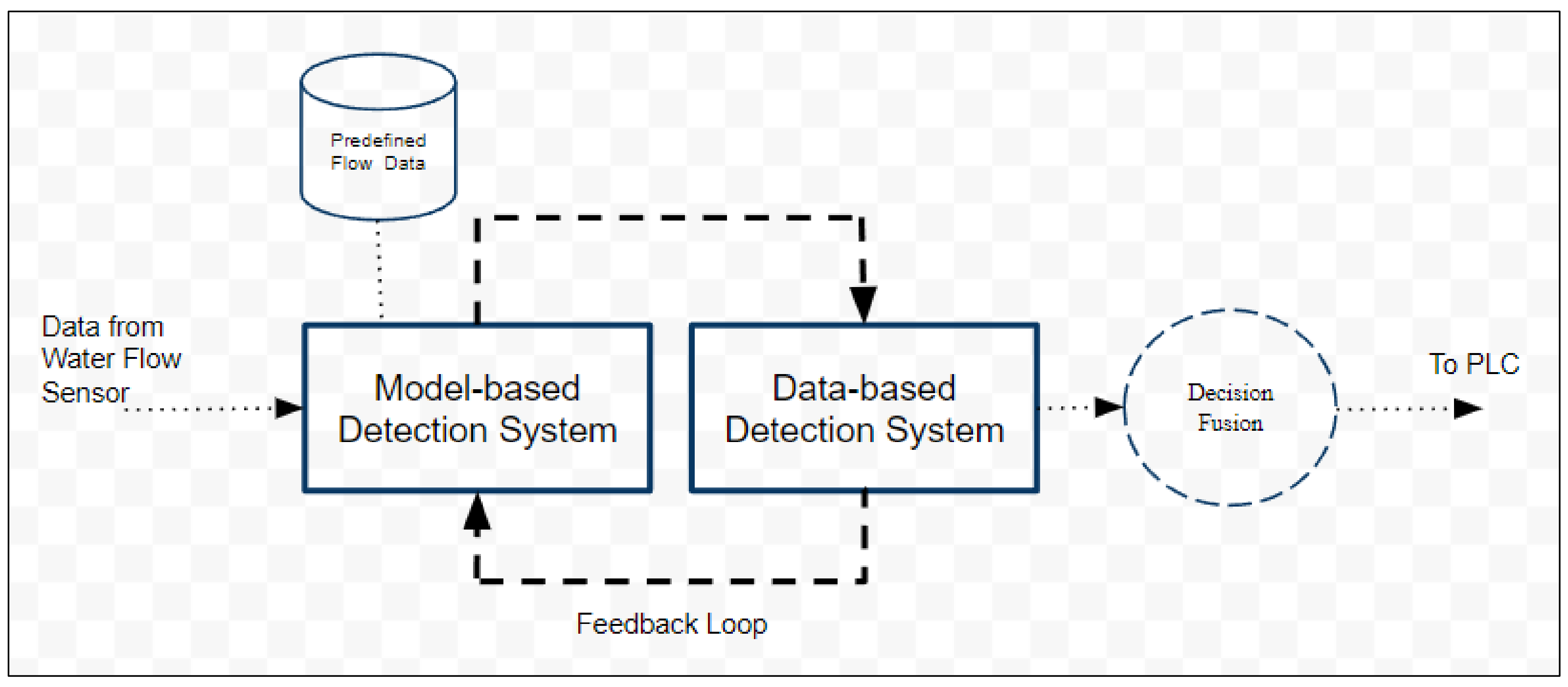

Predefined Flow Data
Data from Water Flow Sensor
Model-based Detection System
Data-based Detection System
Decision Fusion
To PLC
Feedback Loop

Figure 2: Simple PFD of a Cyber-Physical System (CPS) designed to detect and cross-examine flow anomalies

Discussion

Analysis of previous accidents, such as the Stuxnet worm targeting Iranian nuclear facilities in 2010 and the NotPetya ransomware attack in 2017, shows that vulnerabilities most susceptible to attack are present in the Industrial Control Systems (ICS) and the Supervisory Control and Data Acquisition (SCADA) systems, causing anomalies and process failure. To detect anomalies caused by cyber-attacks to processes, we have (2):

- Model-based Detection: A predefined model of the system's behaviour compares real-time sensor data with the expected values generated by the model.
- Data-based Detection: Historical or real-time data is used to identify abnormal patterns or anomalies using Machine Learning (ML) techniques.

While model-based detection is effective in identifying known patterns of cyber-attacks that deviate from the expected system behaviour, surge attacks can manipulate the system too quickly for detection if sensors are compromised. Hence, advanced data-driven methods (using Machine Learning) are crucial for countering intelligent attacks, they are more adaptable to detecting novel or previously unseen cyber-attacks. They can learn and evolve based on new data and emerging threats.

Thus, a collaborative detection system connected through a feedback loop is proposed that uses both systems to combat cyber-threats efficiently.

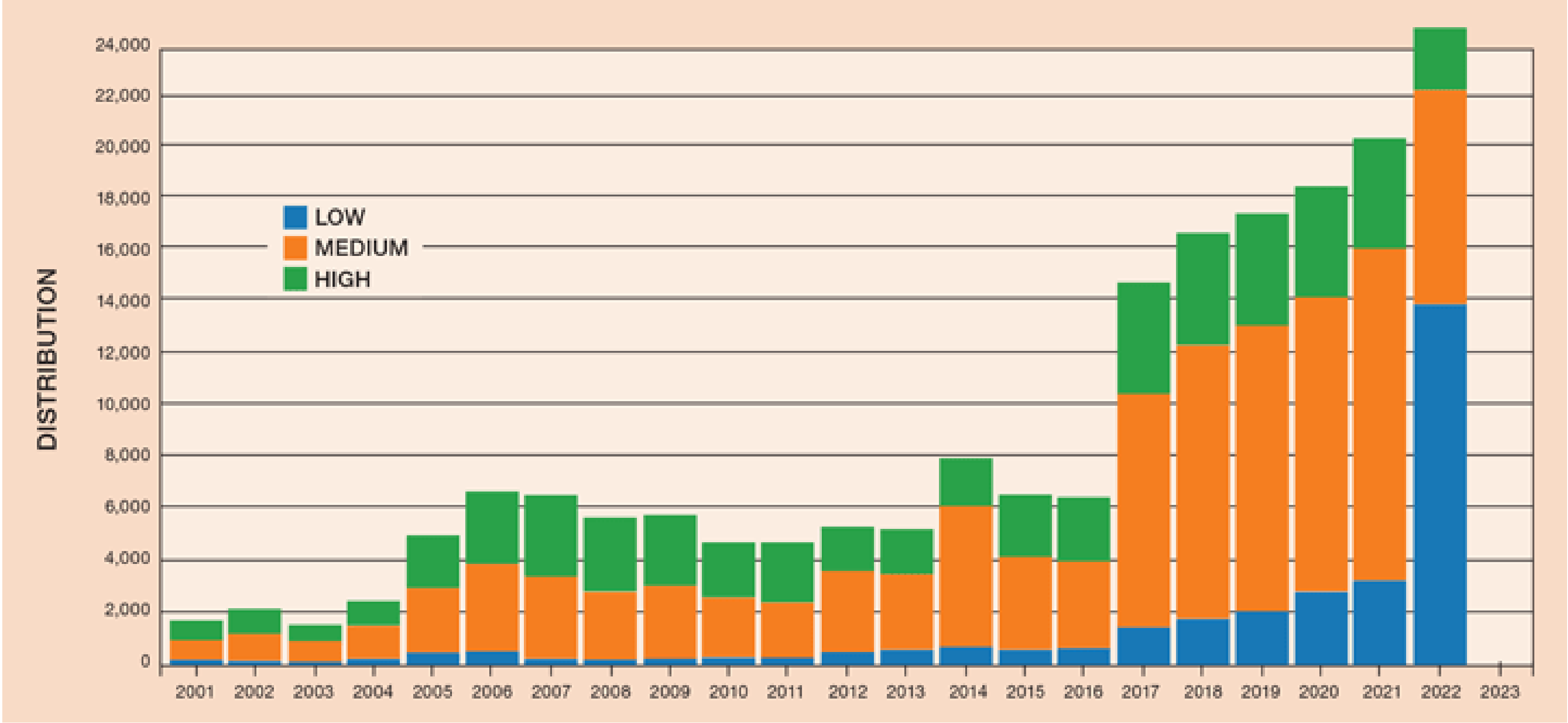


Figure 1: New cybersecurity vulnerabilities discovered each year (1)

Cyber-Physical System (CPS) to intercept Cyber threats

To counter cyber threats in chemical processes, a collaborative two-model detection and control system is proposed- demonstrated using a water level control scenario controlled by Programmable Logic Controllers (PLCs):

1. **Initial Screening with Model-Based Detection**: Quickly identifies deviations from expected system behaviour.
2. **Refinement with Data-Based Detection**: Analyses deviations detected to distinguish genuine threats from false alarms.
3. **Feedback Loop for Continuous Improvement**: Establishes a continuous feedback loop between the two detection systems to refine models and algorithms based on new insights and data.
4. **Decision Fusion for Enhanced Accuracy**: Integrates outputs of both detection systems using decision fusion techniques to make more accurate decisions about potential cyber-attacks, then sent to the PLC.

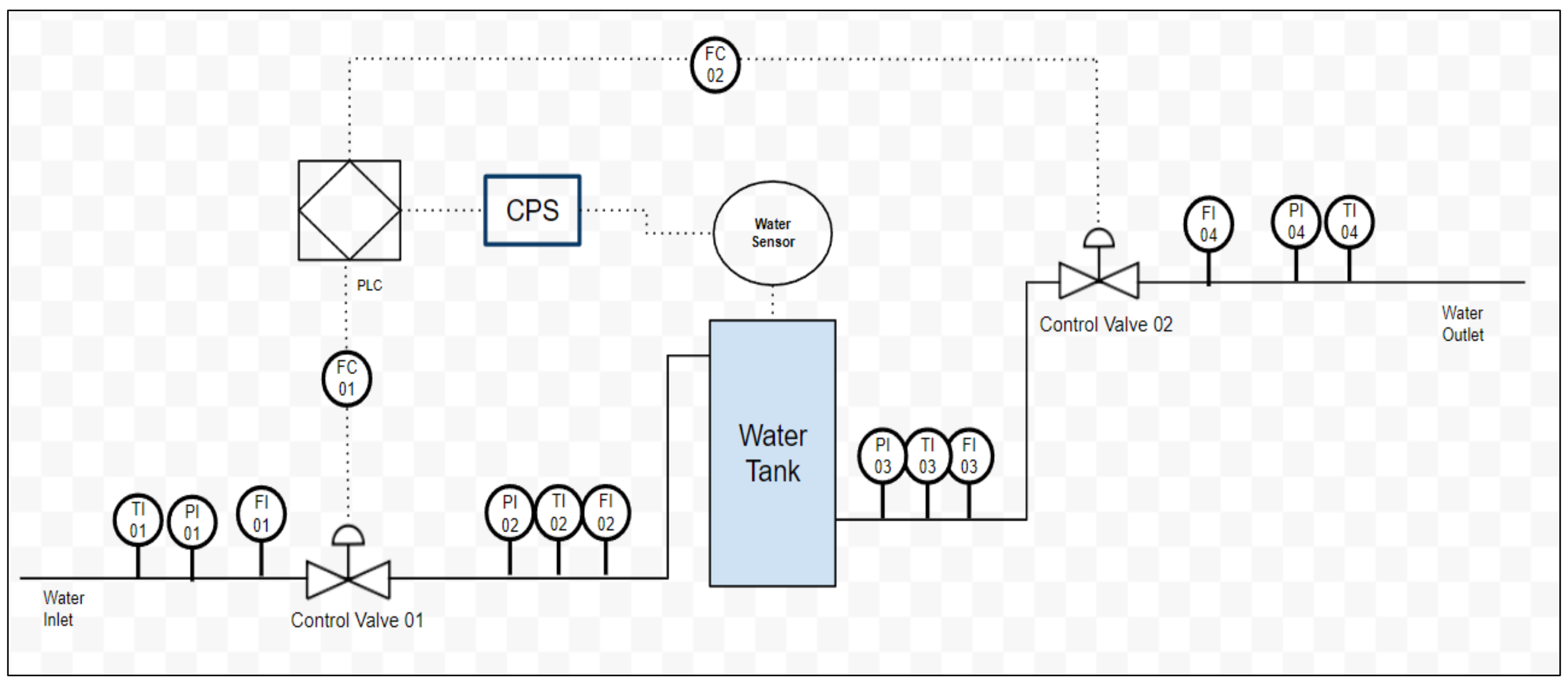


Figure 3: PFD of a Simple Water Flow System designed to show the implementation of a Cyber-Physical System (CPS) to combat cyber threats

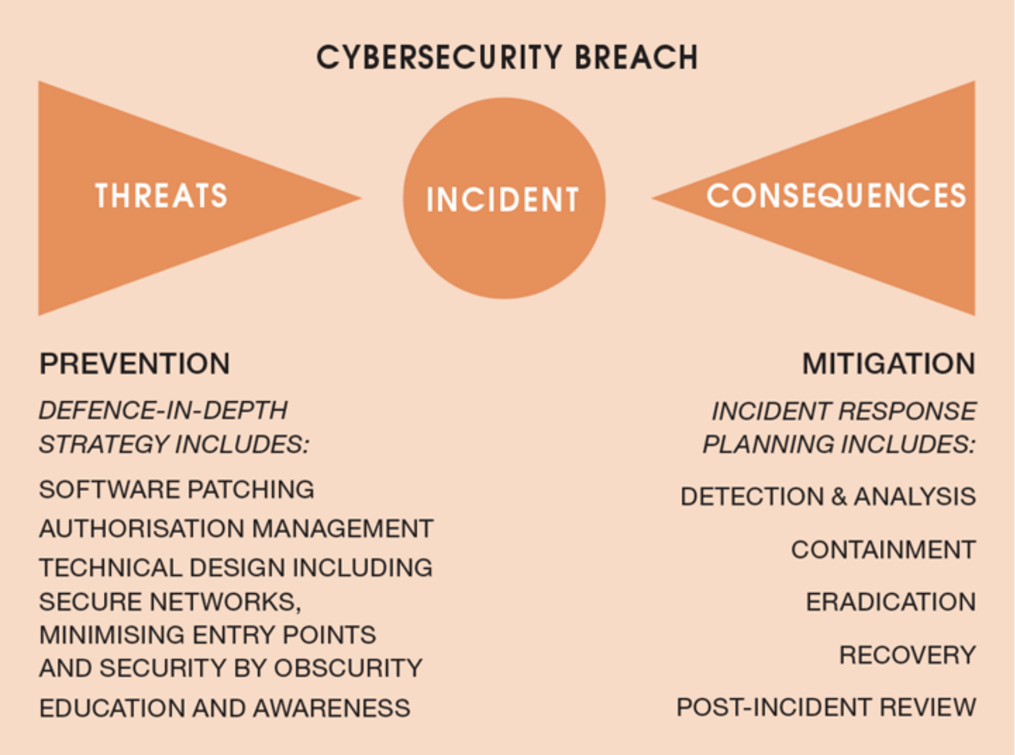
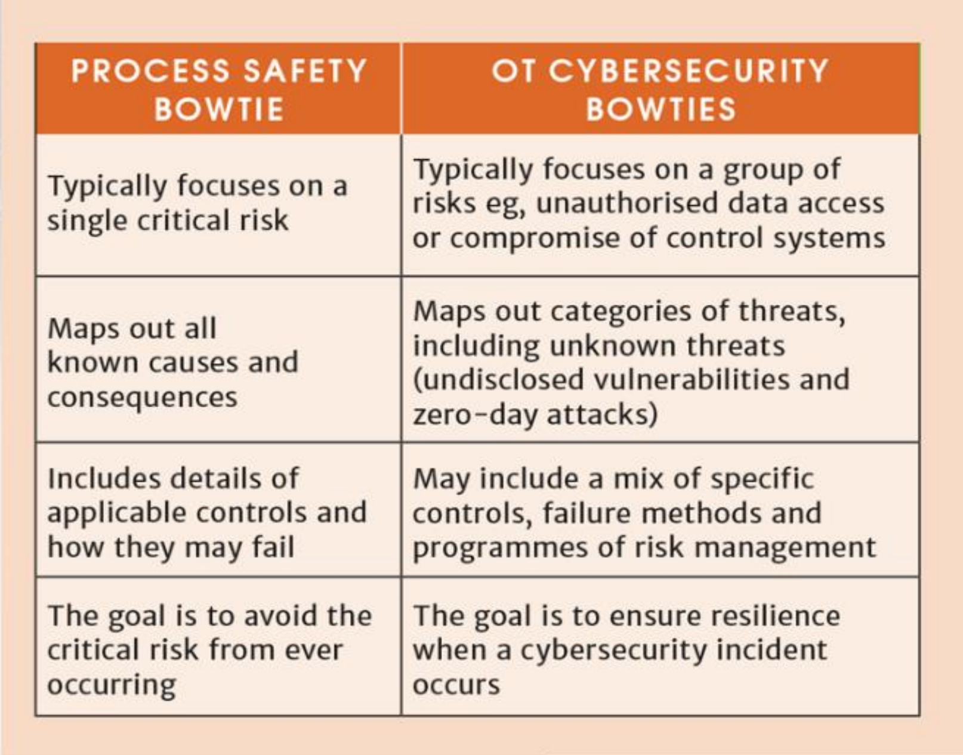


Figure 4: Conceptual cybersecurity bowtie, including examples of cybersecurity breach prevention and mitigation tools (1)



PROCESS SAFETY BOWTIE	OT CYBERSECURITY BOWTIES
Typically focuses on a single critical risk	Typically focuses on a group of risks eg, unauthorised data access or compromise of control systems
Maps out all known causes and consequences	Maps out categories of threats, including unknown threats (undisclosed vulnerabilities and zero-day attacks)
Includes details of applicable controls and how they may fail	May include a mix of specific controls, failure methods and programmes of risk management
The goal is to avoid the critical risk from ever occurring	The goal is to ensure resilience when a cybersecurity incident occurs

Figure 5: Comparison of features for process and OT cybersecurity bowties (1)

Benefits of Cyber Protection to Sustainability Initiatives

Cyber-security measures in chemical processes are pivotal for sustainability.

Pre-emptive mitigation of cyber-attacks through implementation of cyber-security CPS detection systems prevents catastrophic events like toxic leaks, preserving human health and environmental integrity, fortifying public safety and underscoring environmental preservation.

Integrating Industrial Control Systems (ICS) with internet technologies enables remote process control, and when complimented by robust cyber-security system, bolsters operational efficiency and reducing the carbon footprint by minimizing on-site personnel. This diminishes emissions and resource utilization.

Promoting sustainable paradigms through digitalization yields enduring benefits: resource optimization, pollutant abatement, and resilient societal frameworks. Strategic digital initiatives pave the way for a technologically empowered, ecologically sustainable future.

Further Mitigation and Control

Implementation of the proposed control system is to be further supplemented through application of prevention and mitigation bowties (Figure 4 & 5). Establishing incident response procedures, data protection 'defence-in-depth' strategies, accurate asset inventory, and conducting regular cyber-security assessments to ensure compliance to regulations are essential, along with employee and stakeholder training and awareness about common cyber threats and incident reporting procedures (3)(4).

References/Acknowledgements

1. Hunter, Tristan and Gahan, Deaglan. Managing Cybersecurity Risks. The Chemical Engineer. [Online] 2023. https://www.thechemicalengineer.com/features/managing-cybersecurity-risks/.
2. Wu, Zhe, Lee, Cindy and Ventura-Medina, Esther. Integrating Cybersecurity into the Chemical Engineering Curriculum. The Chemical Engineer. [Online] 2024. https://www.thechemicalengineer.com/features/integrating-cybersecurity-into-the-chemical-engineering-curriculum/.
3. Kilbride, Helen . Why Should Cybersecurity Matter to You? The Chemical Engineer. [Online] 2023. https://www.thechemicalengineer.com/features/why-should-cybersecurity-matter-to-you/.
4. IChemE. Data protection strategies and 'defence in depth'. IChemE. [Online] https://www.icheme.org/sustainable-world/priority-topics/digitalisation/cybersecurity-fact-files/data-protection-strategies-and-defence-in-depth/.