By the Numbers: Towards Standard Evaluation Metrics for Programmable Logic Controllers' Defenses

Efrén López-Morales, Jacob Hopkins,
Alvaro Cardenas, Ali Abbasi, and Carlos Rubio-Medrano

2nd International Workshop on Re-design Industrial Control Systems with Security (RICSS)

October 14th, 2024


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In Ukraine, researchers have found the first real-world malware that attacks physical infrastructure since Stuxnet.

Feds Uncover a ‘Swiss Army Knife’ for Hacking Industrial Control Systems

The malware toolkit, known as Pipedream, is perhaps the most versatile tool ever made to target critical infrastructure like power grids and oil refineries.

Background

Programmable Logic Controllers (PLC)

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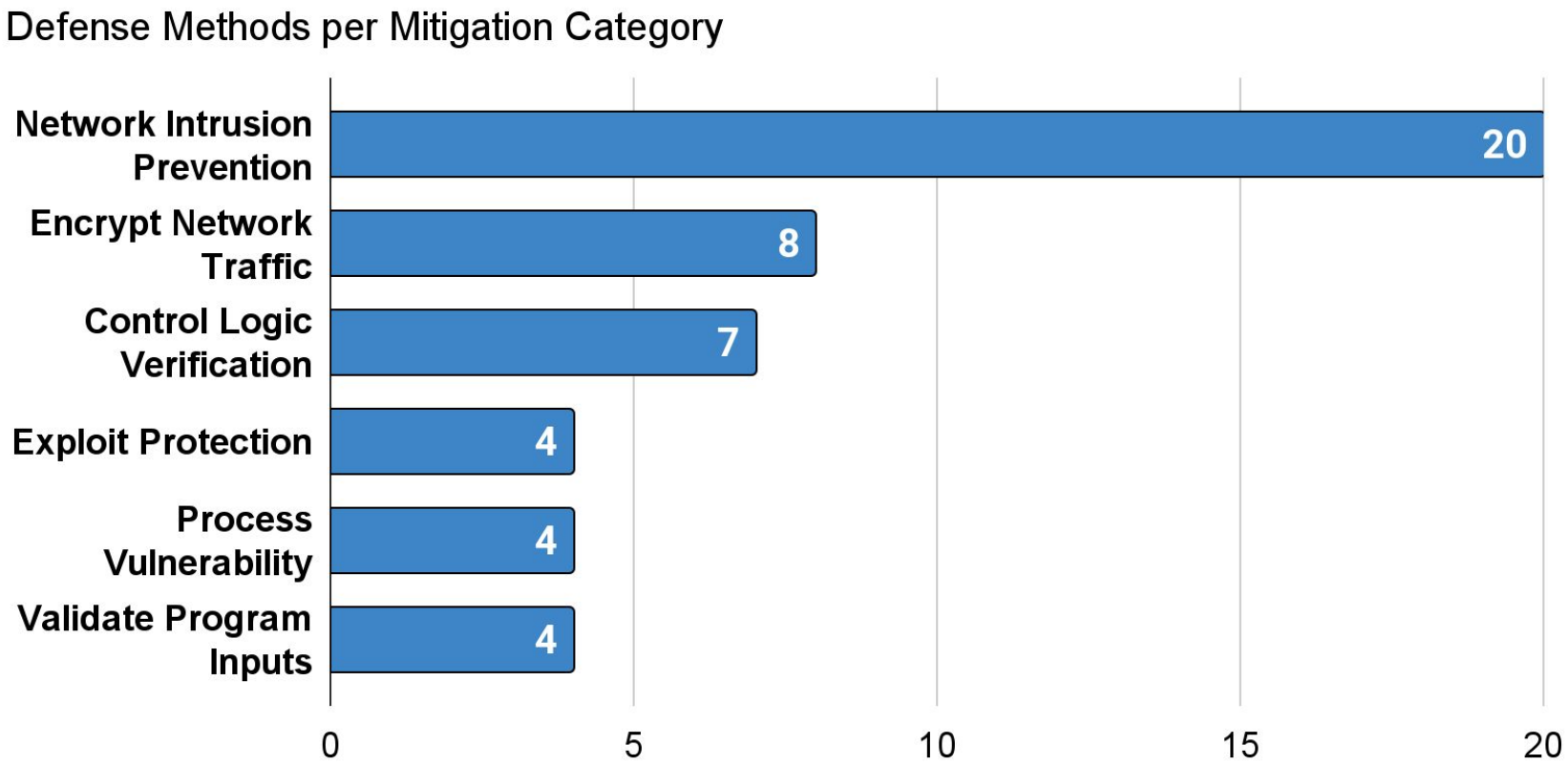
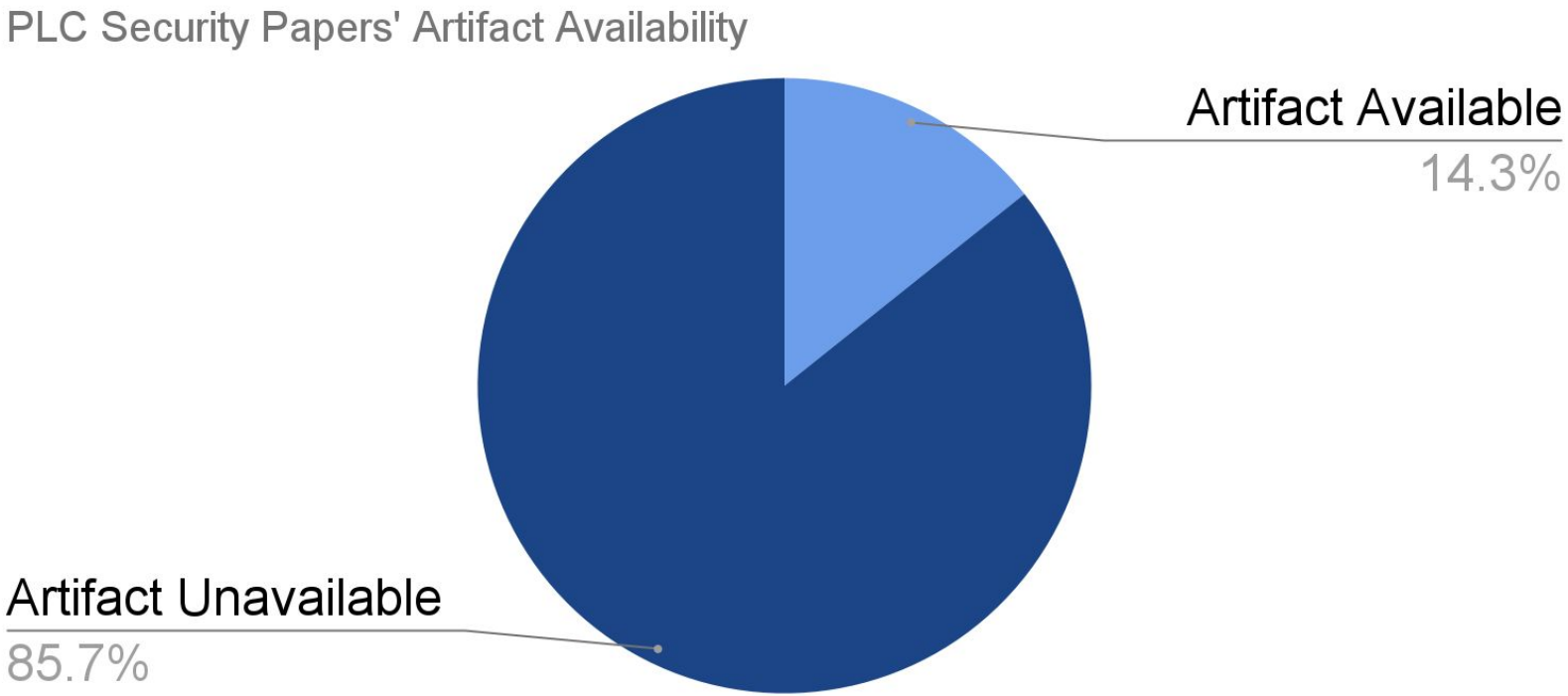
Programmable Logic Controllers (PLC)

- Control physical industrial equipment, e.g., pumps.
- Varied software and hardware architectures.
- Increasingly interconnected, e.g., cloud.
- Yet, little to no built-in security features.



López-Morales, E., Planta, U., Rubio-Medrano, C., Abbasi, A., & Cardenas, A. A. (2024). SoK: Security of Programmable Logic Controllers. 33rd USENIX Security Symposium.

Cockburn, A., Dragicevic, P., Besançon, L., & Gutwin, C. (2020). Threats of a replication crisis in empirical computer science. *Communications of the ACM*, *63*(8), 70-79.



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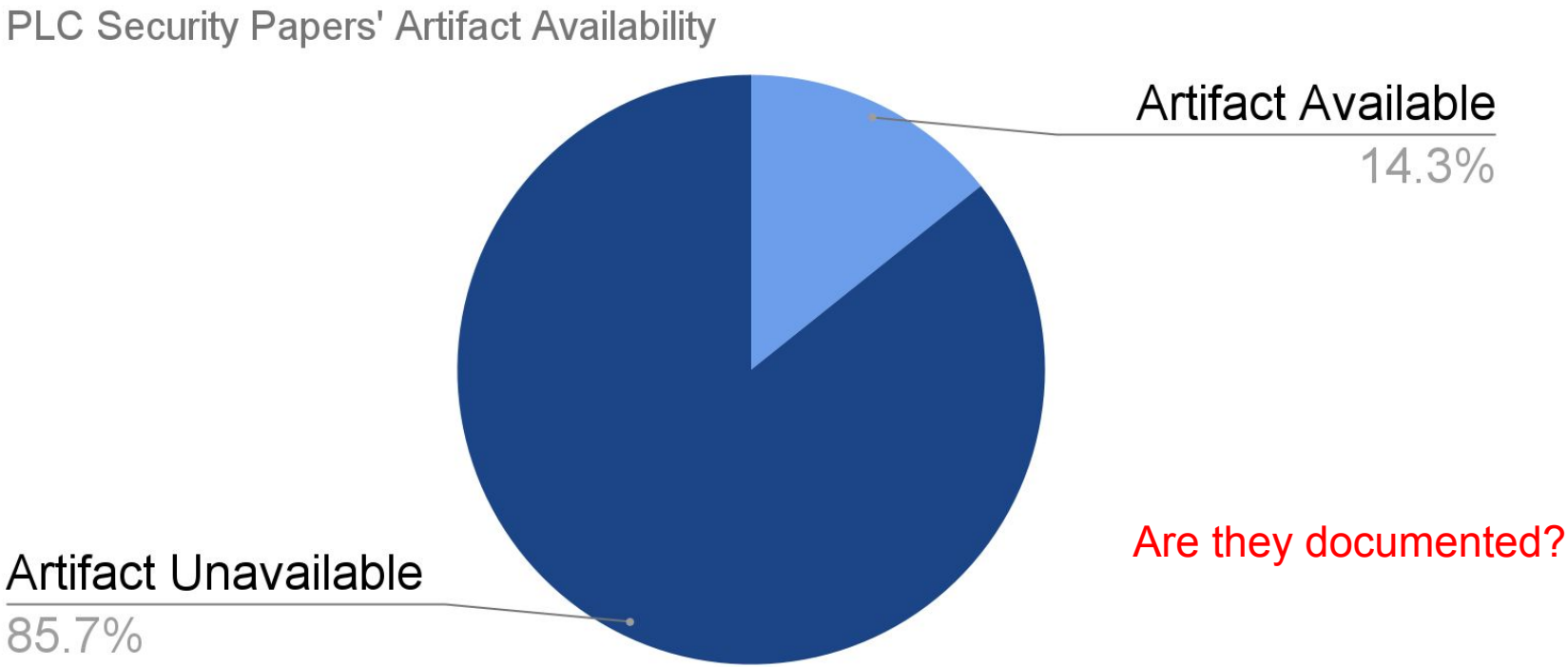

Are they documented?

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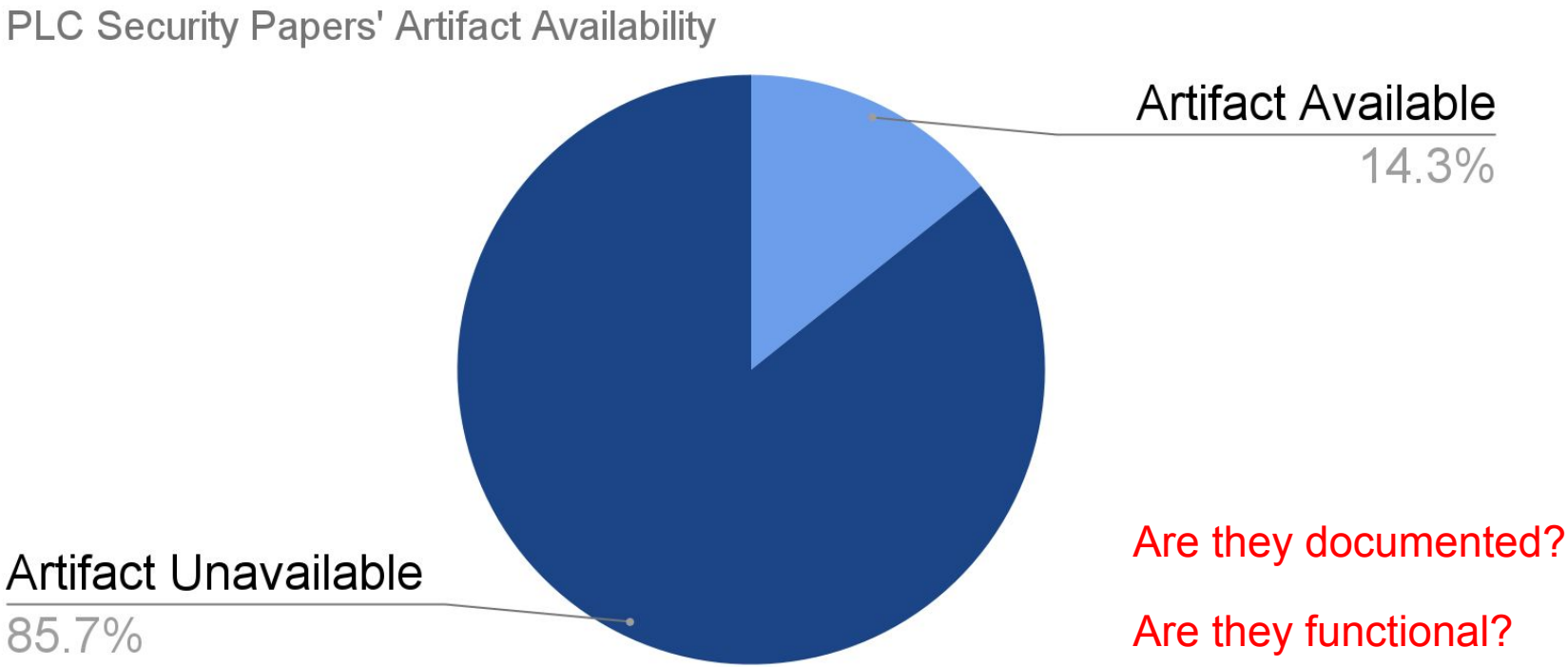

Are they documented?

Are they functional?

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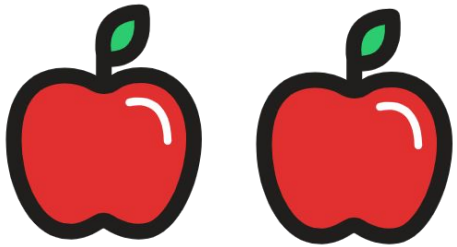
Is there an **alternative** to research artifacts to **improve** PLC security research **reproducibility**?

Evaluation Metrics

Evaluation Metrics

- Provide the **standards** by which different algorithms, systems, or artifacts are **compared**.



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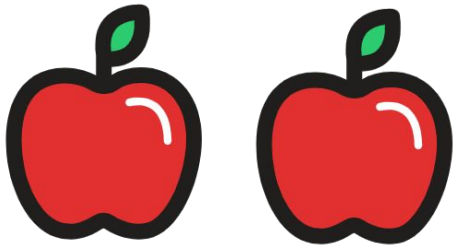

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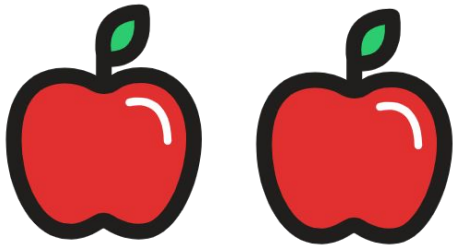
- Provide **quantitative** measures to assess the **performance** of the artifact.
- Do not require access to artifacts.



Existing Evaluation Metrics for PLCs

Overhead

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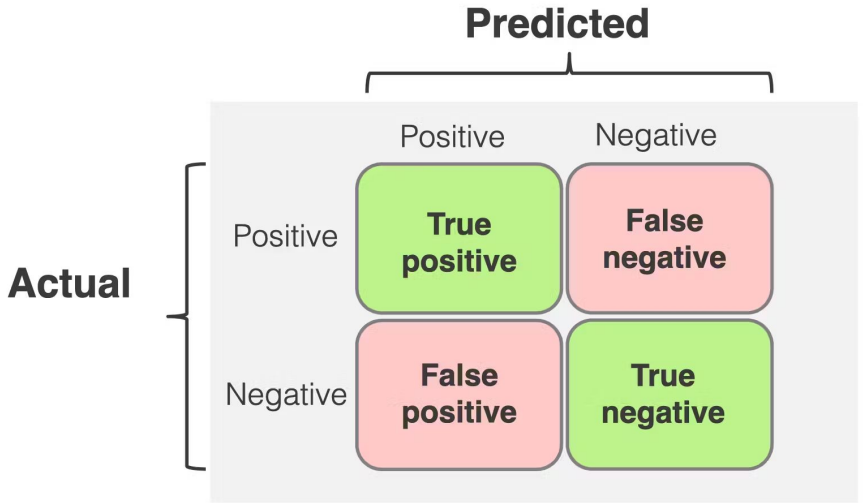
Overhead

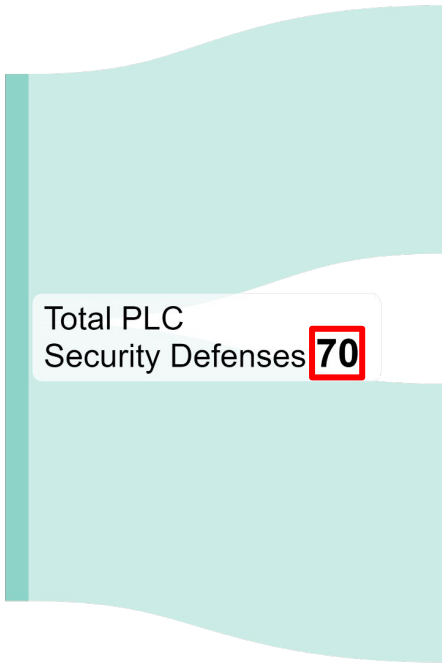
Effectiveness



Existing Evaluation Metrics for PLCs

No security metrics

PLC Defenses Reported Metrics (2007-2023)



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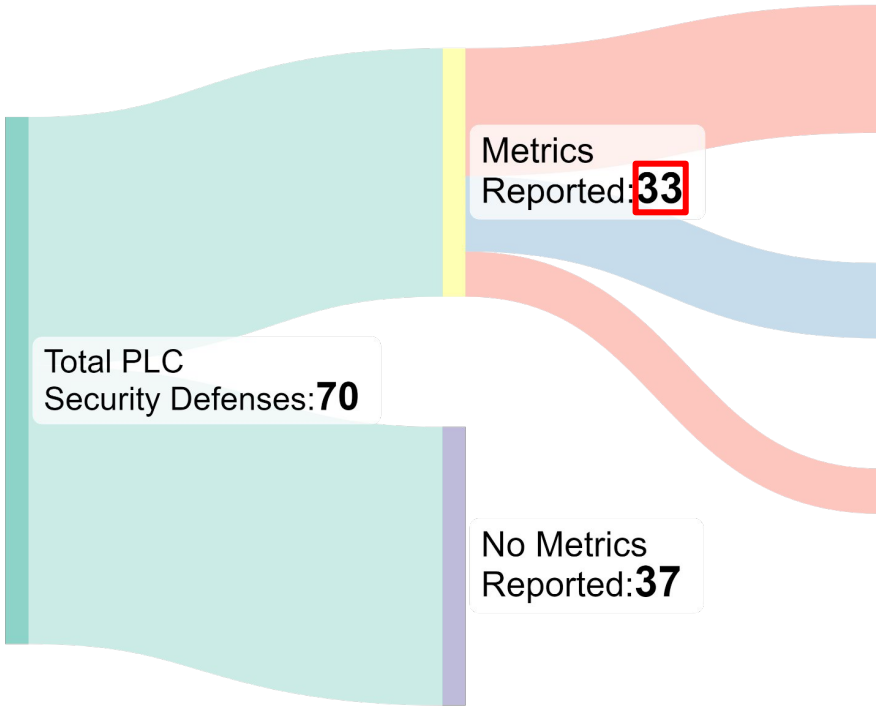

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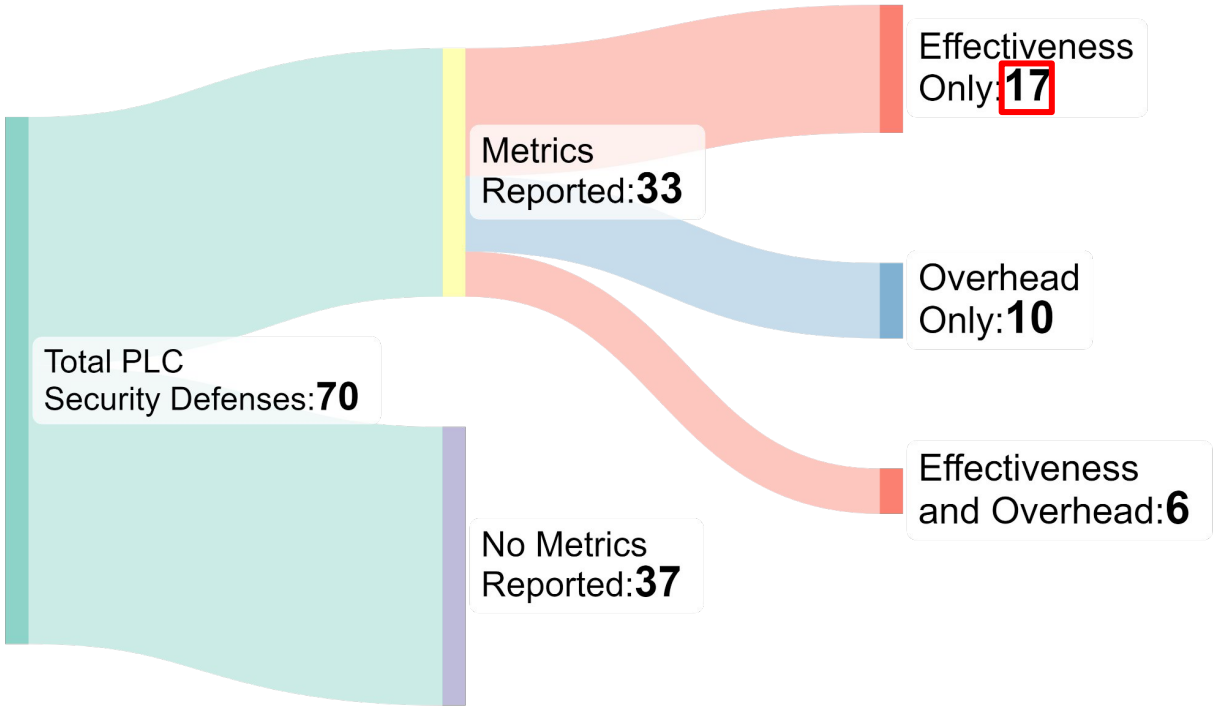

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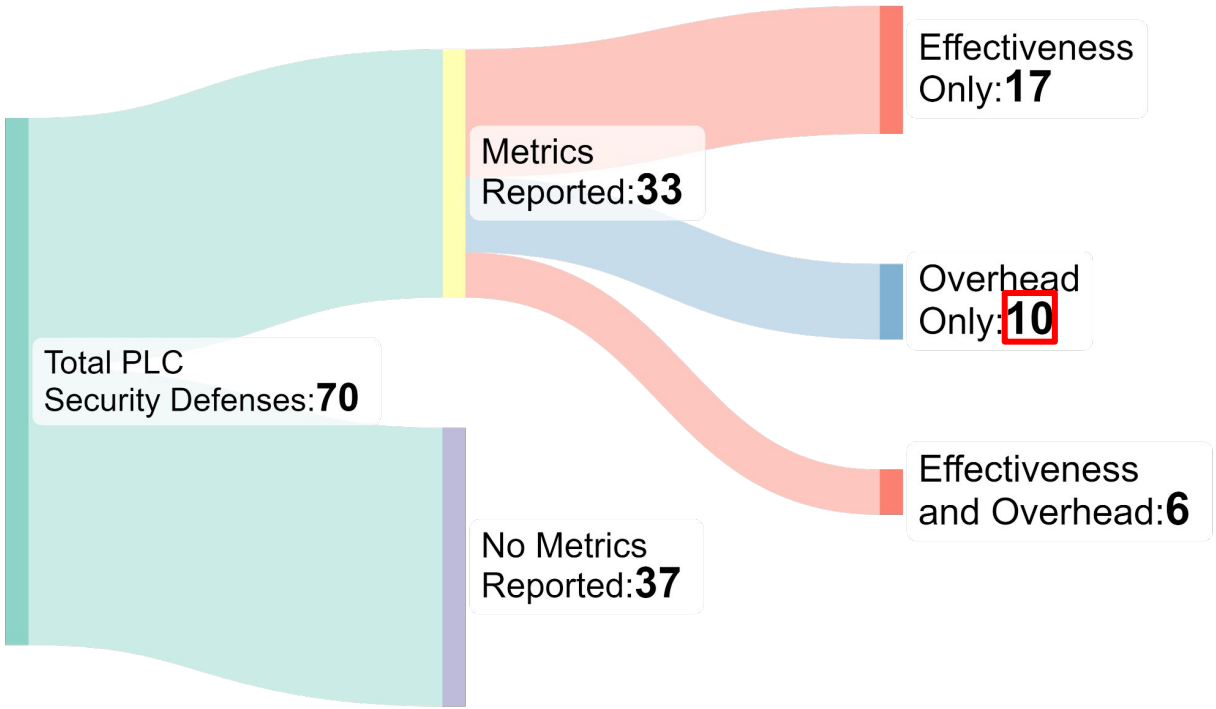

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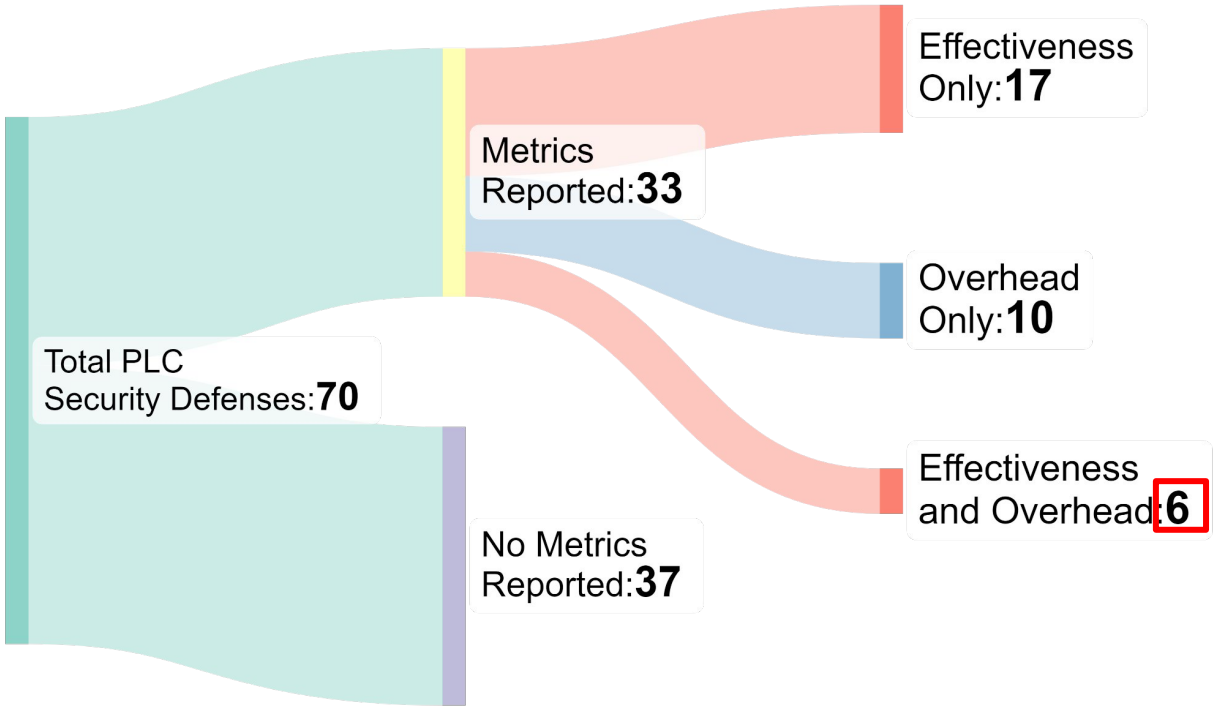

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Main Problem:

Metrics are not being reported and are not standardized

Our contribution:

Set of Standard Evaluation Metrics for PLC Defenses

Research Questions

1. What are the key evaluation metrics for PLC Defenses?

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2. What are the challenges in obtaining these evaluation metrics?

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2. What are the challenges in obtaining these evaluation metrics?

3. How can these challenges be addressed?

How did we select our standard metrics?

Multiple PLC Architectures

CODESYS

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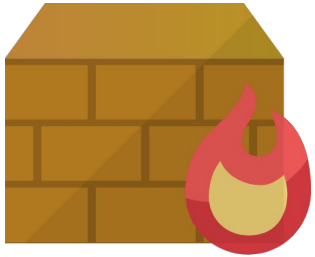
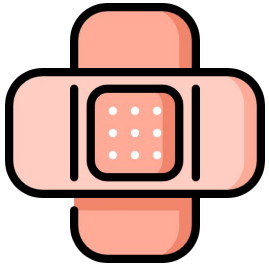
Multiple PLC Architectures

CODESYS

Multiple PLC Defenses





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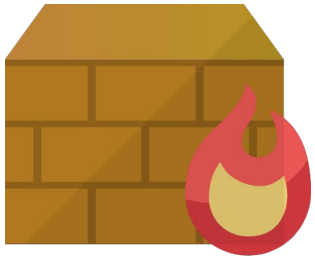
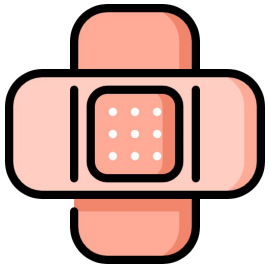




Straightforward

Our Standard Evaluation Metrics

Overhead

Our Standard Evaluation Metrics

Overhead

Security

Our Standard Evaluation Metrics

Overhead

Security

Effectiveness

Our Standard Evaluation Metrics: Overhead

Metric	Unit
Scan Cycle	milliseconds (ms)
Total Runtime Cycles	milliseconds (ms)
CPU Cycles	milliseconds (ms)
Total RAM Usage	Kilobytes (KiB)

Our Standard Evaluation Metrics: Security

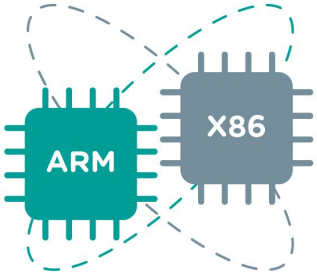
Metric	Unit
ROP Gadgets	Integer
Memory Region Ratio (MRR)	Kilobytes (KiB)
Privileged Cycles	milliseconds (ms)

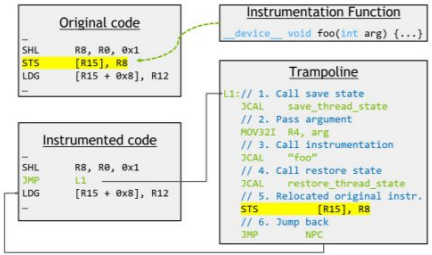
Our Standard Evaluation Metrics: Effectiveness

Metric	Unit
True Positive	Integer
True Negative	Integer
False Positive	Integer
False Negative	Integer
Accuracy	Float

What are the challenges obtaining our evaluation metrics?

No standard benchmarking tool





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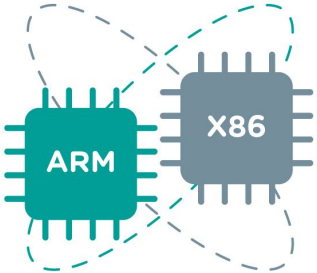

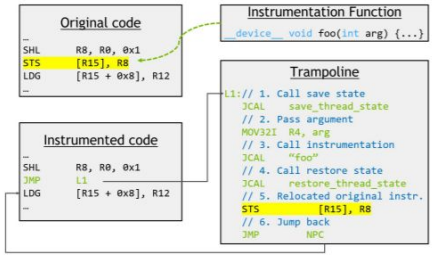

Proprietary Software and Hardware

SIEMENS

Rockwell Automation

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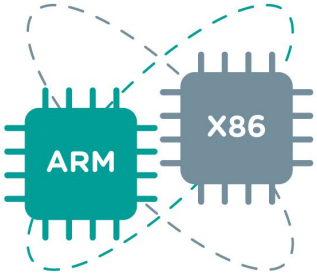

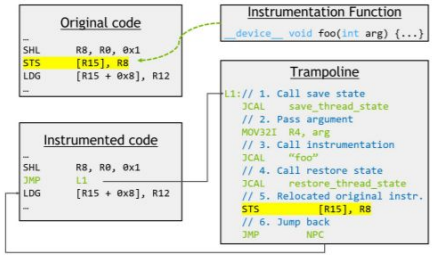

Proprietary Software and Hardware

SIEMENS

Rockwell Automation

Different Environmental Conditions

Recommendation 1: Leverage existing tools

Benchmarking

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Benchmarking

arm Developer

OPENPLC

TO A MORE
OPEN FUTURE

Profiling

SIMATIC Controller
Profiling

TIA Portal

CODESYS Profiler

The CODESYS Profiler enables
level.
The CODESYS Profiler is part of

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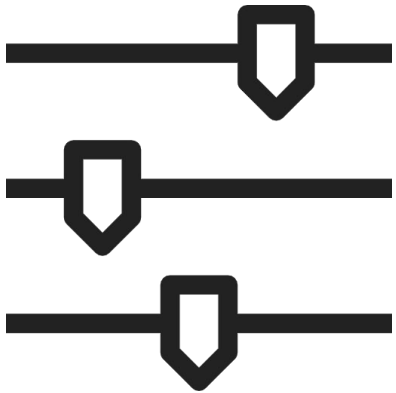
Recommendation 2: Normalize Environment Configuration

Track configuration



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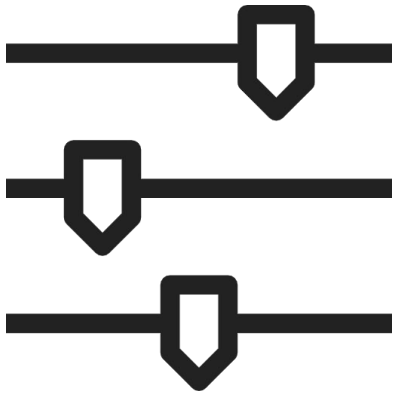
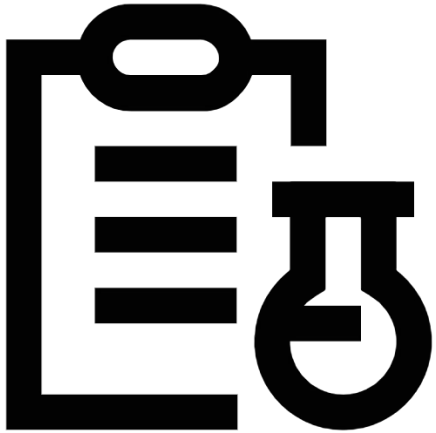
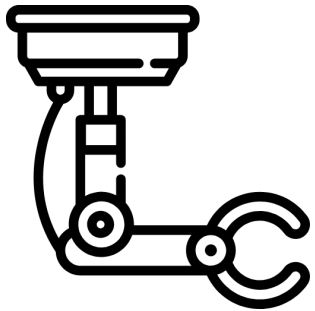


Report in paper



Recommendation 3: Worst-Case Execution Time (WCET)



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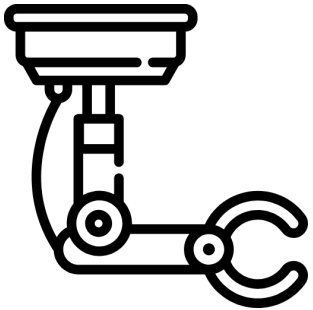

WCET over Average

Future Work

- Develop a PLC defenses **benchmark framework**.

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  - What **PLCs** will be **supported**?

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- We **provided recommendations** on how to measure and report these metrics.
- We hope this work will **serve as a starting point** to improve the current state of evaluation metrics for PLC security.

Thank you!

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CORPUS CHRISTI