NISTIR 8183A
Volume 2

Cybersecurity Framework Manufacturing Profile Low Impact Level Example Implementations Guide:
Volume 2 – Process-based Manufacturing System Use Case

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National Institute of Standards and Technology
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U.S. Department of Commerce
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Walter Copan, NIST Director and Under Secretary of Commerce for Standards and Technology

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Abstract

This guide provides example proof-of-concept solutions demonstrating how available open-source and commercial off-the-shelf (COTS) products could be implemented in process-based manufacturing environments to satisfy the requirements in the Cybersecurity Framework (CSF) Manufacturing Profile Low Impact Level. The example proof-of-concept solutions include measured network, device, and operational performance impacts observed during the implementation. Manufacturers should make their own determinations about the breadth of the proof-of-concept solutions they voluntarily implement. Some important factors to consider include: company size, cybersecurity expertise, risk tolerance, and the threat landscape. The CSF Manufacturing Profile can be used as a roadmap for managing cybersecurity risk for manufacturers and is aligned with manufacturing sector goals and industry best practices. The Manufacturing Profile provides a voluntary, risk-based approach for managing cybersecurity activities and cyber risk to manufacturing systems. The Manufacturing Profile is meant to complement but not replace current cybersecurity standards and industry guidelines that the manufacturer is embracing.

Keywords

Computer security; Cybersecurity Framework (CSF); distributed control systems (DCS); industrial control systems (ICS); information security; manufacturing; network security; programmable logic controllers (PLC); risk management; security controls; supervisory control and data acquisition (SCADA) systems.

Supplemental Content

Additional volumes of this publication include:

NISTIR 8183A Volume 1, *Cybersecurity Framework Manufacturing Profile Low Impact Level Example Implementations Guide: Volume 1 – General Implementation Guidance.* https://doi.org/10.6028/NIST.IR.8183A-1

NISTIR 8183A Volume 3, *Cybersecurity Framework Manufacturing Profile Low Impact Level Example Implementations Guide: Volume 3 – Discrete-based Manufacturing System Use Case.* https://doi.org/10.6028/NIST.IR.8183A-3

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Note to Readers

This guide describes a proof-of-concept solution for securing manufacturing environments that has only been tested in a lab environment. Manufacturers should make their own determinations about the breadth of the proof-of-concept solutions they voluntarily implement. Some important factors to consider include: company size, cybersecurity expertise, risk tolerance, and the threat landscape. We welcome feedback on its contents and your input. Comments, suggestions, and success stories will improve subsequent versions of this guide. Please contribute your thoughts to CSF_Manufacturing_Profile_Implementation@nist.gov.

Revision to Include Updates in Cybersecurity Framework Version 1.1

The Cybersecurity Framework Manufacturing Profile, NISTIR 8183, was drafted and released when the Cybersecurity Framework was at Version 1.0. This guide provides implementation guidance and example proof-of-concept solutions with respect to the language in the original Cybersecurity Framework Manufacturing Profile.

The Cybersecurity Framework Manufacturing Profile, NISTIR 8183, is scheduled to be revised to include the updates in the Cybersecurity Framework Version 1.1, and will be published as NISTIR 8183, Revision 1.

Once NISTIR, 8183, Revision 1 has been released, this implementation guide will be revised to include the updates in the Cybersecurity Framework Version 1.1 as well, and will be published as NISTIR 8183A, Revision 1.

Table of Contents

Executive Summary

This guide provides example proof-of-concept solutions demonstrating how available open-source and commercial off-the-shelf (COTS) products could be implemented in process-based manufacturing environments to satisfy the requirements in the Cybersecurity Framework (CSF) Manufacturing Profile [4] Low Impact Level. A manufacturing system could be classified as Low potential impact if the loss of integrity, availability, or confidentiality could be expected to have a limited adverse effect on manufacturing operations, manufactured product, assets, brand image, finances, personnel, the general public, or the environment. A limited adverse effect means that, for example, the loss of integrity, availability, or confidentiality might:

- result in degradation in mission capability to an extent and duration that the system can perform its primary functions, but the effectiveness of the functions is noticeably reduced,
- result in minor damage to operational assets,
- result in minor financial loss, or
- result in minor harm to individuals.

The example proof-of-concept solutions include measured network, device, and operational performance impacts observed during the implementation. Manufacturers should make their own determinations about the breadth of the proof-of-concept solutions they voluntarily implement. Some important factors to consider include: company size, cybersecurity expertise, risk tolerance, and the threat landscape.

The CSF Manufacturing Profile can be used as a roadmap for managing cybersecurity risk for manufacturers and is aligned with manufacturing sector goals and industry best practices. The Manufacturing Profile provides a voluntary, risk-based approach for managing cybersecurity activities and cyber risk to manufacturing systems. The Manufacturing Profile is meant to complement but not replace current cybersecurity standards and industry guidelines that the manufacturer is embracing.

The CSF Manufacturing Profile focuses on desired cybersecurity outcomes and can be used as a roadmap to identify opportunities for improving the current cybersecurity posture of the manufacturing system. The Manufacturing Profile provides a prioritization of security activities to meet specific business/mission goals. Relevant and actionable security practices that can be implemented to support key business/mission goals are then identified.

While the proof-of-concept solutions in this guide used a suite of commercial products, this guide does not endorse these particular products, nor does it guarantee compliance with any regulatory initiatives. Each organization's information security experts should identify the products that will best integrate with their existing tools and manufacturing system infrastructure. Organizations may voluntarily adopt these solutions or one that adheres to these guidelines in whole or can use this guide as a starting point for tailoring and implementing parts of a solution. This guide does not describe regulations or mandatory practices, nor does it carry any statutory authority.

1. Introduction

The Executive Order 13636, "Improving Critical Infrastructure Cybersecurity," [1] directed the development of the voluntary Cybersecurity Framework that provides a prioritized, flexible, repeatable, performance-based, and cost-effective approach to manage cybersecurity risk [1] for those processes, information, and systems directly involved in the delivery of critical infrastructure services.

The Cybersecurity Framework is a voluntary risk-based assemblage of industry standards and best practices designed to help organizations manage cybersecurity risks [2]. The Framework, created through collaboration between government and the private sector, uses a common language to address and manage cybersecurity risk in a cost-effective way based on business needs without imposing additional regulatory requirements.

To address the needs of manufacturers, a Manufacturing Profile [4] of the Cybersecurity Framework was developed, through collaboration between government and the private sector, to be an actionable approach for implementing cybersecurity controls into a manufacturing system and its environment. The Profile defines specific cybersecurity activities and outcomes for the protection of the manufacturing system, its components, facility, and environment. Through use of the Profile, the manufacturer can align cybersecurity activities with business requirements, risk tolerances, and resources. The Profile provides a manufacturing sector-specific approach to cybersecurity from standards, guidelines, and industry best practices.

1.1 Purpose and Scope

Many small and medium sized manufacturers have expressed challenges in implementing a standards-based cybersecurity program. This guide provides example proof-of-concept solutions demonstrating how available open-source and commercial off-the-shelf (COTS) products could be implemented in process-based manufacturing environments to satisfy the requirements in the Cybersecurity Framework (CSF) Manufacturing Profile Low Impact Level. A manufacturing system could be classified as Low potential impact if the loss of integrity, availability, or confidentiality could be expected to have a limited adverse effect on manufacturing operations, manufactured product, assets, brand image, finances, personnel, the general public, or the environment. A limited adverse effect means that, for example, the loss of integrity, availability, or confidentiality might:

- result in degradation in mission capability to an extent and duration that the system can perform its primary functions, but the effectiveness of the functions is noticeably reduced,
- result in minor damage to operational assets,
- result in minor financial loss, or
- result in minor harm to individuals.

Example proof-of-concept solutions with measured network, device, and operational performance impacts for a process-based manufacturing environment (Volume 2) and a discrete-based manufacturing environment (Volume 3) are included in the guide. Manufacturers should make their own determinations about the breadth of the proof-of-concept solutions they

voluntarily implement. Some important factors to consider include: company size, cybersecurity expertise, risk tolerance, and the threat landscape. The CSF Manufacturing Profile can be used as a roadmap for managing cybersecurity risk for manufacturers and is aligned with manufacturing sector goals and industry best practices. The Manufacturing Profile provides a voluntary, risk-based approach for managing cybersecurity activities and cyber risk to manufacturing systems. The Manufacturing Profile is meant to enhance but not replace current cybersecurity standards and industry guidelines that the manufacturer is embracing.

While the proof-of-concept solutions in this guide used a suite of commercial products, this guide does not endorse these particular products, nor does it guarantee compliance with any regulatory initiatives. Each organization's information security experts should identify the products that will best integrate with their existing tools and manufacturing system infrastructure. Organizations may voluntarily adopt these solutions or one that adheres to these guidelines in whole or can use this guide as a starting point for tailoring and implementing parts of a solution. This guide does not describe regulations or mandatory practices, nor does it carry any statutory authority.

This project is guided by the following assumptions:

- the solutions were developed in a lab environment,
- the environment is based on a typical small manufacturer's environment,
- the environment does not reflect the complexity of a production environment, and
- an organization can access the skills and resources required to implement a manufacturing cybersecurity solution.

1.2 Audience

This document covers details specific to manufacturing systems. Readers of this document should be acquainted with operational technology, general computer security concepts, and communication protocols such as those used in networking. The intended audience is varied and includes the following:

- control engineers, integrators, and architects who design or implement secure manufacturing systems,
- system administrators, engineers, and other information technology (IT) professionals who administer, patch, or secure manufacturing systems,
- managers who are responsible for manufacturing systems,
- senior management who are trying to understand implications and consequences as they justify and implement a manufacturing systems cybersecurity program to help mitigate impacts to business functionality, and
- researchers, academic institutions and analysts who are trying to understand the unique security needs of manufacturing systems.

1.3 Document Structure

Volume 2 is divided into the following major sections:

- Section 2 provides an overview of the process-based manufacturing system use case.
- Section 3 provides the detailed policy and procedure documents developed for the process-based manufacturing system use case.
- Section 4 provides the detailed technical capability implementations and associated performance measurements for the process-based manufacturing system use case.
- Appendix A provides a list of acronyms and abbreviations used in this document.
- Appendix B provides a glossary of terms used in this document.
- Appendix C provides a list of references used in the development of this document.

2. Process-based Manufacturing System Low Impact Level Use Case

2.1 Introduction

This use case is a proof-of-concept demonstrating how available open-source and commercial off-the-shelf (COTS) products could be implemented in a process-based manufacturing environment to satisfy the requirements in the Cybersecurity Framework (CSF) Manufacturing Profile Low Impact Level. Manufacturers should make their own determinations about the breadth of the proof-of-concept solutions they voluntarily implement. Some important factors to consider include: company size, cybersecurity expertise, risk tolerance, and the threat landscape.

2.2 Process-based Low Impact Level Use Case

The fictional company, Westman Industries (i.e. Westman), is a chemical manufacturer producing commercial grade chemical products for use in the transportation, building and construction, and other industries. It is headquartered in Westland, a city with a population of about 100,000 people.

Westman operates its manufacturing facility 24 hours per day, 7 days per week (24/7), except for a scheduled maintenance shutdown for about 2 weeks every year, typically at the end of December.

To increase industrial competitiveness, Westman has introduced process automation equipment to improve production efficiency and to lower production costs. Industrial automation equipment like programmable logic controllers (PLC), human-machine-interfaces (HMI), and data historians are deployed in the factory to monitor and control the production operation.

2.2.1 Mission

Westman's mission is to supply high quality chemical products for industrial application.

2.2.2 Facility

Westman facility is a single building about 5000 m^2, with about 3500 m^2 of manufacturing space which includes the production space, a distribution facility, and several above ground chemical storage tanks. The remainder of the facility contains the administrative and engineering office space.

The perimeter of the facility is fenced, and the main entrance has a gate that is open during business hours and is locked after hours. There are two entrances to the main building. One is for employee access and is protected by a badge access system. Employees must swipe their assigned badge to enter the building. The other entrance is located at the front lobby, staffed by a receptionist during normal business hours. Guests and visitors are required to sign in and receive proper identification before entering the building or facility. The Westman facility does not have any contracted security guards at the gate or entrances.

2.2.3 Employees

Westman has 200 full-time employees, with most of the employees working on the manufacturing floor. A small team of full-time manufacturing/control engineers is responsible for the manufacturing, control and automation equipment controlling the manufacturing process. Their mission is to ensure the safe and efficient operation of the production system.

Westman also has a small team of full-time IT personnel responsible for the enterprise IT systems.

Westman's senior managers have the following positions and responsibilities:

Westman Management	Major Responsibility
Chief Executive Officer (CEO)	Oversight of the company
Director of Operations	Oversight of manufacturing operations. Management of the manufacturing staff and control engineers. Reports to the CEO.
Director of Product Development	Oversight of product development. Management of the on-site chemists. Reports to the CEO.
Director of Marketing	Oversight of marketing and sales. Reports to the CEO.
Controller/Finances	Manager of finance staff. Reports to the CEO.
General Counsel	Handles all legal matters. Reports to the CEO.
IT Manager	Manager of IT staff. Reports to the CEO.
HR Manager	Manager of human resources staff. Reports to the CEO.

2.2.4 Supply Chain

Raw materials are utilized to support the continuous operation of the manufacturing process. Raw materials are typically supplied through a long-term contract established with suppliers and are transported to the facility on a regular basis.

The end products are typically sold to customers in large quantity. Delivery is sub-contracted to several logistics companies which will handle the transportation from the Westman facility to the end customers. Westman's products are typically used as raw materials or additives in chemical processes performed by other industrial manufacturers.

2.2.5 Supporting Services

The supporting services required by Westman are electricity, natural gas, water, and Internet. The broadband Internet connection is a business class service provided by a large national provider with business class service level agreement.

2.2.6 Legal and Regulatory Requirements

As a chemical manufacturer, Westman and its employees are required to comply with all federal and state legal and regulatory requirements for chemical and hazardous materials. Westman is also required to comply with all legal, regulatory and safety requirements.

2.2.7 Critical Infrastructure

The chemical sector is considered a critical infrastructure under the Presidential Policy Directive 21 (PPD-21).

2.2.8 Manufacturing Process

The manufacturing system consists of five major chemical processing components: a reactor, a product condenser, a vapor-liquid separator, a recycle compressor, and a product stripper to separate the end products. The manufacturing system has 12 valves for controlling the flow of chemicals through the system, and 41 sensor measurements for monitoring the chemical process. All valves and sensors are connected to the automation equipment (PLCs) through a DeviceNet communications bus. Valves are equipped with manual overrides, enabling workers to override the automation equipment during an emergency.

Raw materials are fed to the reactor where the materials are mixed and the main reaction takes place. Output from the reactor flows downstream to the product condenser and the vapor-liquid separator. Any output from the reactor still in the gaseous form is recycled through a compressor and fed back into the main reactor. All condensed components continuously flow to the product stripper, which separates the components into the final products. Quality assurance samples are taken at various stages of the process to validate the product quality and process efficiency.

2.2.9 Systems

The administrative office is supported by a small team of IT personnel mainly using general enterprise IT applications (e.g., email, web applications, and enterprise planning applications).

The IT personnel maintain a central file storage that is used to store source code, chemical formulas, drawings, procedures, and diagrams, and is backed up regularly. The product development staff and the manufacturing engineers are authorized to access this storage.

The IT personnel also installed and configured a Historian database on the manufacturing floor to record manufacturing process data. IT personnel are responsible for regular data backup of the Historian, and the manufacturing engineers are responsible for the configuration and operation of the Historian.

2.2.10 Data

Data transferred over, or stored within the company network include:

- PLC program code
- Chemical formulas and calculations
- Workflow and operating manuals and documentation
- Electrical diagrams
- Network diagrams
- Quality Assurance procedures
- Historical production data

NOTE: All data listed above are considered proprietary, trade secrets, or sensitive.

2.2.11 Network

The IT systems within the administrative offices are connected to the corporate network, which is managed by the IT team. The manufacturing floor has a separate network for automation equipment and is managed by the manufacturing engineers.

The manufacturing network consists of a typical Ethernet based TCP/IP network and other industrial protocols, e.g., DeviceNet.

Some of the production equipment vendors require Westman to provide remote access to the equipment. The remote access allows the authorized vendors to connect to the manufacturing equipment to provide maintenance and support.

2.2.12 Mission Objectives

Maintain Personnel Safety

Westman commits to safe operation of the manufacturing system and to always put personnel safety as its highest priority. All manufacturing processes, protocols, automation processes and equipment, operating procedures and guidelines are designed to ensure personnel safety.

Maintain Environmental Safety

Westman complies with all applicable regulations regarding environmental safety. Westman is committed to ensuring environmentally-friendly operation of its manufacturing process and working to reduce its environmental footprint. Environmental impact caused by the manufacturing process is measured and reviewed on a quarterly basis.

Maintain Quality of Product

Westman has a world-class manufacturing facility and process. It has employed state of the art automation, equipment, and techniques to ensure the high quality of its products. It has developed a quality assurance program using automation equipment, including PLCs, Historian, and high precision sensors operating on a high-speed control network to monitor product quality.

Maintain Production Goals

Meeting the monthly production goals is an important objective for Westman and ensures the supply of products to its customers in a timely fashion. It also maintains financial stability for Westman.

Constant 24/7 production enables Westman to plan its manufacturing operation to meet its production goals and customer demand. The investment in automation equipment and skilled professionals enables Westman to maintain the monthly production goals.

Protect Trade Secrets

Westman is committed to protecting its trade secrets, including product development, manufacturing processes, product quality, and supply chain management.

3. Policy and Procedure Implementations

This section includes example policy and procedure documents and statements that were developed for the fictional company Westman. Each organization's information security experts should identify the policy and procedure documents and statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

3.1 Cybersecurity Program Document Example

This section provides example content that a Cybersecurity Program document may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

Cybersecurity Program

for

Westman

Document Owner:	Director of Operations

Version

Version	Date	Description	Author
1.0	02-22-2018	Initial Draft	Director of Operations
2.0	04-21-2018	Major changes to the initial draft	Director of Operations

Approval

(By signing below, approvers agree to all terms and conditions outlined in this document.)

Approvers	Role	Signed	Approval Date
S. Forthright	CEO	<digital signature>	4-22-2018
M. West	General Counsel	<digital signature>	4-23-2018

3.1.1 Purpose

The Cybersecurity Program establishes guidelines and principles for initiating, implementing, maintaining, and improving cybersecurity management for Westman.

This program is designed to:

- ensure the security and confidentiality of employees and business information,
- protect against any anticipated threats or hazards to the security or integrity of such information, and
- protect against unauthorized access to or use of such information that could result in substantial harm or inconvenience to Westman, its partners, or customers.

3.1.2 Audience

This document is intended to be used by the CEO, IT Manager, Director of Operations and any other members as deemed appropriate by the management. It supports the company's responsibility for implementing a cybersecurity program.

3.1.3 Commitment from Management

Westman's leadership team is committed to the development of this Information Security Program. It fully supports and owns the ultimate responsibility of this program. This commitment involves allocating necessary funding to information security work and responding without delay to new situations. The leadership team will participate in any information security related event.

3.1.4 Company Overview

Role in the Industrial sector

Westman is a chemical manufacturer producing commercial grade chemical products for use in the transportation, building and construction, and other industrial products.

Westman operates its manufacturing facility 24 hours per day and 365 days per year, except for a scheduled maintenance shutdown for about 2 weeks every year, typically at the end of December. To increase competitiveness, Westman has introduced process automation equipment to improve the production efficiency and to lower cost. Industrial automation equipment like Programmable Logic Controller (PLC), Human-Machine-Interface (HMI), and Data Historian are deployed in the factory to control and monitor the production operation.

The chemical sector is considered a critical infrastructure under the Presidential Policy Directive 21 (PPD-21).

Mission Objectives

1. Maintain Personnel Safety
   Westman commits to safe operation of the manufacturing system and to always put personnel safety as its highest priority. All manufacturing processes, protocols, automation processes and equipment, operating procedures and guidelines are designed to ensure personnel safety.

2. Maintain Environmental Safety
   Westman complies with all applicable regulations regarding environmental safety. Westman is committed to ensuring environmentally-friendly operation of its manufacturing process and working to reduce its environmental footprint. Environmental impact caused by the manufacturing process is measured and reviewed on a quarterly basis.

3. Maintain Quality of Product
   Westman has a world-class manufacturing facility and process. It has employed state of the art automation, equipment, and techniques to ensure the high quality of its products. It has developed a quality assurance program using automation equipment, including PLCs, Historian, and high precision sensors operating on a high-speed control network to monitor product quality.

4. Maintain Production Goals
   Meeting the monthly production goals is an important objective for Westman and ensures the supply of products to its customers in a timely fashion. It also maintains financial stability for Westman.

   Constant 24/7 production enables Westman to plan its manufacturing operation to meet its production goals and customer demand. The investment in automation equipment and skilled professionals enables Westman to maintain the monthly production goals.

5. Protect Trade Secrets
   Westman is committed to protecting its trade secrets, including product development, manufacturing processes, product quality, and supply chain management.

Role in the Supply chain

Raw materials are supplied through a long-term contract established with suppliers and are transported to the facility on a regular basis.

The end products are typically sold to customers in a large quantity. Delivery is sub-contracted to several logistics companies which will handle the transportation from the Westman facility to the end customers. Westman's products are typically being used as raw materials or addictive for other industrial manufacturers

Communication to Company

All critical and operational aspects of the Manufacturing system, key resources should be documented in network diagrams, manuals or other artifacts. The documentation will be reviewed on a yearly basis by the Director of Operations with assistance from the IT Manager. This information will be shared with all employees and contractors depending on their role in the company.

Critical Manufacturing System Components

Critical manufacturing system components are defined as the following:

- Engineering workstation
- Supervisory PLC
- HMI Server
- OPC and Controller Server
- Historian Database Server
- Network devices

Supporting Services

The supporting services required by Westman are broadband Internet, electricity, natural gas, and water supply. The broadband Internet connection is a business class service provided by a national provider with a business class service level agreement.

3.1.5 Information Security Policy

The purpose of this Information Security Policy is to provide an overview of the policies, standards, procedures and technical controls that make up Westman's Information Security Program. This policy is developed and executed by the Director of Operations, and has expectations set for protecting Westman's IT and Operational Technology (OT) assets.

3.1.6 Applicable Laws and Regulations

As a chemical manufacturer, Westman is required to comply with all federal and state legal or regulatory requirements for chemical and hazardous materials. Westman is also required to comply with all legal, regulatory and safety requirements as an employer.

3.1.7 Security Organization and Governance

Information security is an inherent part of governance and consists of the leadership, organizational structures and processes that safeguard Westman's information, its operations, its market position, and its reputation.

Organizational Role	Security Responsibilities
Chief Executive Officer (CEO)	• Reviewing and approving the information security program and supporting policies, at least annually. • Assigning the Director of Operations responsibility for organization's policies and procedures for use of any IT/OT assets, implementation, documentation and for meeting its compliance obligations. • Serve as Point of Escalation for any incidents. • Responsible for coordinating data breach response.
Controller / Finances	• Report any cybersecurity incidents and concerns to the Director of Operations
Control Engineers	• Report any cybersecurity incidents and concerns to the Director of Operations. • Help with the cybersecurity requirements for their specific area. • Assist in remediating vulnerabilities if asked by the Director.
Director of Marketing	• Report any cybersecurity incidents and concerns to the Director of Operations
Director of Product Development	• Report any cybersecurity incidents and concerns to the Director of Operations
Director of Operations	• Responsible for overall cybersecurity of all IT/OT assets. • Responsible for remediating vulnerabilities and/or mitigating any risks. • Develop, implement and maintain the Cybersecurity Program and the Cybersecurity Policy documents. • Act as a liaison between operators, vendors, and management on matters relating to information security. Acting as a liaison between plant operators, vendors and management on matters relating to information security. • Report to the CEO about the status of the Cybersecurity Program and cybersecurity related risks or incidents.
IT Manager and IT Team	• Remediate vulnerabilities as directed by the Director of Operations. • Report any cybersecurity incidents, operational issues, and concerns to the Director of Operations. • Assist with the cybersecurity requirements for their specific business unit and area of expertise.

	• Inform the Director of Operations if a cybersecurity incident involves a data breach of sensitive information.
General Counsel	• Handling of any legal matters regarding cybersecurity incidents. • Review external communications related to cybersecurity incidents. • Report any cybersecurity incidents and concerns to the Director of Operations
HR Manager	• Handling of any personnel and disciplinary issues relating to cybersecurity incidents. • Report any cybersecurity incidents and concerns to the Director of Operations

All employees, contractors and vendors are responsible for ensuring the security, confidentiality, and integrity of information by complying with all corporate policies and procedures

3.1.8 Privacy of Personal Information

Employees have no expectation of privacy on Westman systems. All activity on Westman systems and network is subject to monitoring. Westman is a private organization and any information stored on its information systems may be subject to disclosure under state law. Westman will disclose information about individuals only to comply with applicable laws, regulations or valid legal requests.

3.1.9 Operational Security

Risk Management:

The Director of Operations shall conduct yearly risk assessments to identify potential internal and external risks to the security, confidentiality and integrity of Westman.

Risk assessment involves evaluating risks and their likelihood along with selecting and implementing controls to reduce risks to an acceptable level. Each risk assessment documents major findings and risk mitigation recommendations.

All employees are encouraged to report any potential or existing risks to the Director of Operations. Once the Director of Operations has identified or acknowledged the risks, the next course of action will be determined (e.g., accept the risk, seek assistance from the IT Team, contact a vendor to remediate the risk). Similarly, a vendor or contractor can also notify the Director of Operations if they identify any threats or risks to their equipment. A detailed description of risk notification process can be found in Section 3.4 Risk Management Document.

Physical Security:

The perimeter of the facility is fenced, and the main entrance has a gate that is open during business hours and locked after hours. There are two entrances to the main building. One is for employees only which is normally locked, employees must swipe their company-issued identification to enter the building. The other entrance located at the front lobby is open during normal business hours. Guests and visitors are required to sign in with proper identification.

Additionally, personnel security is addressed through pre-employment screenings, adequate position descriptions, terms of employment, and cybersecurity education and training. Additional details regarding physical security requirements are mentioned in Section 3.2.6 Physical Security of the Cybersecurity Policy.

Access Control:

Access to IT and OT systems is based on the principle of least privilege depending on the user's role in the organization. Proper authorization and approval by the Director of Operations are required prior to granting access or operating any components of the manufacturing system. Controls are in place to restrict access through authentication methods and other technical means. Passwords are managed through a formal process and secure log-on procedures. Sensitive systems are explicitly identified and audited regularly.

Appropriate authentication controls are used for external connections and remote users. Physical and logical access to critical components are controlled. Duties are separated to protect systems and data and access rights are audited at regular intervals.

3.1.10 Cybersecurity Awareness Training

Cybersecurity awareness information is provided to new employees at the time of hire. Online resources are provided to educate employees on best practices and the importance of reporting cybersecurity incidents. Additionally, the Director of Operations will ensure the employee understands their role and responsibilities in Westman's Cybersecurity Program.

Any information about potential or existing cyber threats to Westman's systems may be exchanged routinely between the Director of Operations and external vendors. Likewise, any news about email scams, phishing attempts and other malicious actions are posted to inform users of possible threats.

Training for Users and Managers

Employees must perform online computer-based training or classroom-based training per management approval. Below is an example list of potential training options. Trade organization subscriptions to newsletters and magazines will offer more industry specific training classes.

Example Training

- ICS-CERT VLP[1] (Virtual Learning Portal)
- SCADAhacker[2]
- SANS Industrial Control Systems Training[3]
- ISA Training[4]

Training for Privileged Users

Training for privileged users includes the assigned training for regular users. Advanced training will be provided from industry trade groups specializing in automation or other specialty training organization focusing on cybersecurity for ICS environments.

Example Training

- International Society of Automation (ISA)[5]
- SANS (Information Security Training)[6]

Training for Third Party contractors

Third party contractors must complete cybersecurity awareness training before they are allowed to access any IT/OT systems. Training can be completed in person at a training facility, or online in a virtual classroom environment.

Example Training

- SANS Industrial Control Systems Training[7] (training with instructors – fee applies).
- ICS-CERT VLP[8] (Virtual Learning Portal) (virtual classroom environment at no cost).

[1] https://ics-cert-training.inl.gov
[2] https://scadahacker.com/training.html
[3] https://ics.sans.org/training/courses
[4] https://www.isa.org/training-and-certification/isa-training/security-cybersecurity-and-ansi-isa99-training-courses/
[5] https://www.isa.org
[6] https://www.sans.org
[7] https://ics.sans.org/training/courses
[8] https://ics-cert-training.inl.gov

3.1.11 Third Party Responsibilities and Requirements

1. Third party contractors and vendors are required to comply with the Cybersecurity Policy to protect sensitive information and to ensure sensitive information is secured.
2. Third party contractors and vendors will be re-evaluated yearly from the date of completion of the first security compliance check. During this re-certification process, all objectives listed in the Security Awareness Training section above will be revisited to ensure compliance.
3. All remote connections from third party providers will be conducted using a desktop sharing program. These connections will be monitored and audited.
4. All software and hardware tools used on the network must be approved by the Director of Operations before they can be used or deployed.
5. Any data that will be shared requires a documented memorandum of understanding to be executed by both parties.
6. Network accounts will only be created and enabled as required. Accounts used by vendors for remote access require approval from the Director of Operations. Refer to Remote Maintenance Approval in the Cybersecurity Policy document for additional details on the approval process.

3.1.12 Fire Protection, Safety, and Environmental Systems

All fire and safety systems for protecting the manufacturing system must comply with local, state, and federal laws. This is to include safety regulations for workers' safety from Occupational Safety and Health Administration (OSHA). Industry regulations for safety will be followed per guidance from the regulating industry. Any fire protection systems must be designed to protect human life as a first priority, and manufacturing equipment as a second priority. Fire protection for the manufacturing system must be safe to use around electrical equipment (e.g., PLCs, HMIs, robots, servers). Fire protection systems must be certified compliant by a licensed and accredited vendor.

All environmental systems (e.g., HVAC) used in the manufacturing system environment must be compliant with all local, state, and federal laws, and must be designed to protect human life as a first priority, and manufacturing equipment as a second priority.

3.1.13 Emergency Power

A short-term uninterruptible power supply (UPS) is used to facilitate both an orderly shutdown and transition of the organization to a long-term alternate power in the event of a major power loss.

3.1.14 Incident Management

Westman's Incident Response Plan and System Recovery Plan describe the detection, analysis, containment, eradication, recovery and review of cybersecurity incidents. The process for responding to cybersecurity incidents is designated in the Incident Response Plan, while the procedures for system recovery and resilience requirements are defined in the System Recovery Plan. Cybersecurity incidents are managed by the Director of Operations who ensures that cybersecurity incidents are promptly reported, investigated, documented and resolved in a manner that restores operation quickly and, if required, maintains evidence for further disciplinary, legal, or law enforcement actions. The Incident Response Plan and System Recovery Plans are reviewed annually and updated as required.

Lessons learned from cybersecurity incidents will be used to revise and improve detection capabilities while increasing protection for the organization and manufacturing system.

3.1.15 Information Sharing Plan

Information sharing with outside entities like trade organizations and local, state, and federal agencies can help strengthen cybersecurity. Information sharing, especially when receiving information from other outside entities, will improve situational awareness, and result in a more secure manufacturing system.

Trade Organizations

Relationships will be established with trade organizations. These relationships will be used to share information regarding cybersecurity incidents detected within the manufacturing facility. Information shared with trade organizations regarding cybersecurity incidents must have all proprietary information and trade secrets removed. This information will be listed as unclassified. Information regarding a cybersecurity incident containing information relating to proprietary, customer, or trade secret process will require a Non-Disclosure Agreement (NDA) before data is transmitted; this would be considered sensitive information requiring approval from executive management before being sent.

Local Government

Relationships shall be established with local government with the primary purpose to share cybersecurity incident data.

State Government

Relationships shall be established with any state government organization with the primary purpose to share cybersecurity incident data. Trade organizations should be able to provide contact information for state government incident sharing organizations, if they exist.

Federal Government

Relationships shall be established with federal government agencies whose purpose is to share cybersecurity incident data. Some federal government agencies are listed below.

- DHS (CISA)[9] Agency for reporting incidents of Phishing, Malware, Vulnerabilities.
- DHS (NCCIC)[10] Agency for reporting cybersecurity incidents relating to Industrial Control Systems.

3.1.16 Periodic Reevaluation of the Program

The Cybersecurity Program document will be continuously updated to reflect changes made to the manufacturing system and to improve cybersecurity. Lessons learned will be incorporated to help improve this document in the event a cybersecurity incident occurs.

The Director of Operations shall reevaluate and modify the Program from time to time as deemed appropriate. The Director of Operations shall base such reevaluation and modification on the following:

- The results of the risk assessment and monitoring efforts
- Any material changes to Westman's operations, business or infrastructure components
- Any cybersecurity incident

3.1.17 Additional Resources

1. Implementing Effective Information Security Program by SANS Resources[11]
2. InfoSec Program Plan by University of Tennessee Knoxville[12]
3. GCADA Sample Information Security Procedure[13]
4. IT Security Program by Old Dominion University[14]

[9] https://www.us-cert.gov/report
[10] https://ics-cert.us-cert.gov/Report-Incident
[11] https://www.sans.org/reading-room/whitepapers/hsoffice/designing-implementing-effective-information-security-program-protecting-data-assets-of-1398
[12] https://oit.utk.edu/wp-content/uploads/2015-11-11-utk-sec-prog-plan.pdf
[13] http://www.gcada.org/pdf/Sample%20Information%20Security%20Procedure%20(safeguard%20policy).pdf
[14] https://www.odu.edu/content/dam/odu/offices/occs/docs/odu-it-security-program.pdf

3.2 Cybersecurity Policy Document Example

This section provides example content that a Cybersecurity Policy document may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

Cybersecurity Policy

for

Westman

Document Owner:	Director of Operations

Version

Version	Date	Description	Author
1.0	02-22-2018	Initial Draft	Director of Operations
2.0	04-21-2018	Major changes to the initial draft	Director of Operations

Approval

(By signing below, approvers agree to all terms and conditions outlined in this document.)

Approvers	Role	Signed	Approval Date
S. Forthright	CEO	<digital signature>	4-22-2018

3.2.1 Purpose

This Cybersecurity Policy defines the security requirements for the proper and secure use of IT and OT services in the organization. The goal of the defined policies is to protect the organization and its users against cybersecurity threats that could jeopardize the integrity, privacy, reputation, and business outcomes of the company.

3.2.2 Scope

This Cybersecurity Policy applies to any employee, contractor, or individual with access to the manufacturing system, or its data.

3.2.3 Policy Maintenance

The Cybersecurity Policy must be approved by the Director of Operations in consultation with the IT Manager and CEO before it can be disseminated to employees. Any updates to this document must also be approved by the Director of Operations.

This policy document will be reviewed by the Director of Operations on an annual basis and will notify all employees of any updates made to the policy.

3.2.4 Role-based Cybersecurity Responsibilities

Cybersecurity responsibilities vary depending on an individual's role in the company. Each is defined below.

Employees

Organizational Role	Security Responsibilities
Chief Executive Officer (CEO)	• Reviewing and approving the information security program and supporting policies, at least annually. • Assigning the Director of Operations responsibility for organization's policies and procedures for use of any IT/OT assets, implementation, documentation and for meeting its compliance obligations. • Serve as Point of Escalation for any incidents. • Responsible for coordinating data breach response.
Controller / Finances	• Report any cybersecurity incidents and concerns to the Director of Operations
Control Engineers	• Report any cybersecurity incidents and concerns to the Director of Operations. • Help with the cybersecurity requirements for their specific area. • Assist in remediating vulnerabilities if asked by the Director.
Director of Marketing	• Report any cybersecurity incidents and concerns to the Director of Operations
Director of Product Development	• Report any cybersecurity incidents and concerns to the Director of Operations

Director of Operations	• Responsible for overall cybersecurity of all IT/OT assets. • Responsible for remediating vulnerabilities and/or mitigating any risks. • Develop, implement and maintain the Cybersecurity Program and the Cybersecurity Policy documents. • Act as a liaison between operators, vendors, and management on matters relating to information security. Acting as a liaison between plant operators, vendors and management on matters relating to information security. • Report to the CEO about the status of the Cybersecurity Program and cybersecurity related risks or incidents.
IT Manager and IT Team	• Remediate vulnerabilities as directed by the Director of Operations. • Report any cybersecurity incidents, operational issues, and concerns to the Director of Operations. • Assist with the cybersecurity requirements for their specific business unit and area of expertise. • Inform the Director of Operations if a cybersecurity incident involves a data breach of sensitive information.
General Counsel	• Handling of any legal matters regarding cybersecurity incidents. • Review external communications related to cybersecurity incidents. • Report any cybersecurity incidents and concerns to the Director of Operations
HR Manager	• Handling of any personnel and disciplinary issues relating to cybersecurity incidents. • Report any cybersecurity incidents and concerns to the Director of Operations

External Personnel

Role	Security Responsibilities
Equipment Vendor	• Assist in remediating vulnerabilities, upgrading software or hardware as required. • Comply with Westman cybersecurity policy.
Visitor	• Comply with Westman cybersecurity policy.

3.2.5 Employee requirements

1. Employees must complete cybersecurity awareness training and agree to uphold the acceptable use policy.
2. Employees must immediately notify the Director of Operations if an unescorted or unauthorized individual is found in the facility.
3. Employees must always use a secure password on all systems as per the password policy. These credentials must be unique and must not be used on other external systems or services.
4. Terminated employees must return all company records, in any format.
5. Employees must verify with the Director of Operations that authorizations have been granted before allowing external personnel to connect to the IT or OT network.
6. Employees must report any physical or cybersecurity incidents to the Director of Operations.

3.2.6 Physical Security

1. Employees must always use and display company-provided physical identification (ID).
2. IDs must be designed to enable the immediate visual distinction between employees, external personnel, and visitors.
3. Sharing of IDs for any reason is strictly prohibited.
4. A sign-in sheet will be maintained by the receptionist to record all Visitor visits. These log records will be reviewed periodically by the Director of Operations.
5. Any visitors, contractors and/or maintenance personnel must always be escorted by an employee.
6. Unauthorized removal of any company documentation, equipment, or media from the facility is restricted, unless authorized by the Director of Operations.
7. All activities of visitors, contractors, and maintenance personnel will be subject to monitoring while onsite. The Director of Operations, or a designated employee, will be assigned to monitor all computer activities if the visitor, contractor, or maintenance personnel is connected to any company network.
8. Monthly security status monitoring of the company will be conducted to check for any physical security incidents.

3.2.7 Information Technology (IT) Assets

1. IT assets must only be used for the business activities they are assigned and authorized to perform.
2. Every employee is responsible for the preservation and proper use of the IT assets they have been assigned.
3. IT assets must not be left unduly exposed.
4. Desktops and laptops must be locked if left unattended. This policy should be automatically enforced whenever possible.
5. IT assets must not be accessed by non-authorized individuals. Authorization can be obtained from Director of Operations.
6. Configuration changes are to be conducted through the change control process, identifying risks and noteworthy implementation changes.
7. All assets must be protected by authentication technologies (e.g., passwords).
8. Passwords must follow the password policy.
9. The Director of Operations must be notified immediately after an asset is discovered to be lost or stolen.
10. Use of personal devices to access IT resources is prohibited.
11. Storage of sensitive information on portable media is prohibited, unless authorized by the Director of Operations.
12. Any sensitive information stored on IT assets, or being transported on a portable device, must be protected in such a way to deny unauthorized access, and must be encrypted in line with industry best practices and any applicable laws or regulations.

IT Asset Inventory

Description	Quantity
SuperMicro Servers	6
Allen Bradley 5700 Switches	2
Allen Bradley 8300 Router	1
HP Tower Workstation	1

3.2.8 Operational Technology (OT) Assets

1. OT assets must not be used for operations they are not assigned or authorized to perform.
2. The Director of Operations and Operators are responsible for the preservation and correct use of the OT assets they have been assigned.
3. Physical access to OT assets is forbidden for non-authorized personnel.
4. All personnel interacting directly with OT assets must have proper training.
5. The Director of Operations is responsible for all OT devices. A Control Engineer is solely responsible for maintenance and configuration of the OT devices. No other personnel are authorized to modify OT asset configurations, including any modification to interfacing hardware or software.
6. Usage of security tools on the OT network must be approved by the Director of Operations.
7. All operators must be notified before security tools are used on the OT network.
8. Concept of least privilege must be followed when authorizing access to OT assets.
9. OT assets, such as PLCs, safety systems, etc., should have their keys in the "Run" position at all times unless being actively programmed.
10. Accessing IT devices or internet use from the OT network, or OT assets, unless authorized, is prohibited.
11. Use of personal devices to access OT resources is prohibited.

OT Asset Inventory

Description	Quantity
Allen Bradley ControlLogix PLC	1

OT Assets Inventory

3.2.9 Lifecycle Accountability of Assets

1. Any IT or OT asset that needs to be decommissioned must be sanitized of all data, as per the manufacturer guidelines. This task will be usually performed by the IT Support staff.
2. In case of an employee termination, an IT asset such as a desktop PC or laptop must be reimaged prior to assigning it to a different employee.

3.2.10 System Maintenance

1. Any maintenance tasks involving external personnel (e.g., contractors, vendors) must be approved by the Director of Operations.
2. External personnel with access to company resources must properly secure any resources that are used to access Westman networks or systems.
3. All remote maintenance activities will be controlled and monitored to ensure no harmful or malicious activities occur. Detailed logging of the activity will be performed by an employee.
4. All systems and technical controls must be verified upon the completion of maintenance for any cybersecurity related impact.
5. The Director of Operations will log all maintenance activities in a Maintenance Tracker.

3.2.11 Data

1. Access to sensitive data must be authorized by the Director of Operations.
2. Data must not be shared informally. When access to sensitive information is required, personnel can request access from the Director of Operations and should take all necessary steps to prevent unauthorized access.
3. The Director of Operations must immediately be notified in the event a device is lost containing sensitive data (e.g. mobiles, laptops, USB devices).
4. Encrypted portable media or secure protocols must be used while transporting or transferring sensitive company data.
5. Extra precautions must be taken by remotely-operating employees to ensure sensitive data is appropriately protected.
6. Physical copies of data should be stored in a secure location when not in use.
7. Personnel should ensure physical copies of sensitive data are not left unattended (e.g., on a printer or a desk).
8. Physical copies of sensitive data should be shredded or disposed in a secure manner when no longer required.

Data types considered sensitive, proprietary, or containing trade secrets

Description	Digital Files	Physical Copies	Databases
PLC program code	✓		
Chemical formulas	✓	✓	
Quality Assurance Procedures	✓	✓	
Operating manuals and documentation	✓	✓	
Electrical diagrams	✓	✓	
Network diagrams	✓	✓	
Historical production data	✓		✓

3.2.12 Credentials Management

The purpose of this policy is to establish a standard for the creation of strong passwords, protection of those passwords, frequency of change and employee expectations.

All staff, vendors, contractors or other stakeholders who use Westman's IT and OT systems should be given authenticated access to those systems by assigning individual credentials [username and password]. All access and restrictions to those access will be controlled by these credentials.

The creation and removal of IT system accounts is managed via Microsoft Active Directory. In addition, the IT manager will determine and authorize user access to IT or OT systems.

Westman reserves the right to suspend without notice access to any system or service.

3.2.13 Password Policy for Active Directory Accounts

1. All passwords must be at least 10 characters long and contain a combination of upper-case and lower-case letters, numbers, and special characters.
2. Passwords must be changed every 90 days and cannot match a password used within the past 12 months.
3. Passwords must not be a dictionary name or proper name.
4. Passwords must not be inserted into email messages or other forms of electronic communication.
5. Employees must choose unique passwords for all company accounts and may not use a password that they are already using for a personal account.
6. Whenever possible, use of multi-factor authentication is recommended.

7. Default passwords, such as those preconfigured in newly-procured assets, must be removed before the asset is installed or connected to any organizational network.
8. Sharing of passwords is forbidden.
9. Passwords must not be revealed or exposed to public sight.
10. Personnel must refrain from writing passwords down.
11. Personnel must not use the "remember password" feature prevalent on many applications.

3.2.14 Privileged Accounts

Privileged Users

1. The Director of Operations has privileged access to the manufacturing system within Westman.
2. The IT Manager has privileged access to the IT infrastructure within Westman.
3. All other privileged user accounts are granted to individuals on a case-by-case basis by the Director of Operations.

Responsibilities

1. Any privileged user within the manufacturing environment will have two accounts. A primary account used for normal activities, and a privileged "administrator" account for performing privileged functions.

    - Primary accounts are used for normal daily operations.
    - Primary accounts will have the same rights as a standard Westman user account (e.g., email access, Internet access).
    - Privileged accounts will have administrative privileges and must only be used when performing administrative functions within the manufacturing system (e.g., system updates of firmware or software, system reconfigurations, device restarts).

2. Privileged users will adhere to securely using Administrative accounts when performing duties within the manufacturing system. If a privileged account becomes compromised this could have a damaging impact on the manufacturing process.

3.2.15 Antivirus

1. Antivirus will be installed on all devices that are able to support this protection (e.g., workstations and servers) and be configured to limit resources consumed as not to impact manufacturing system production.
2. Installed antivirus will be configured to receive push updates from a central management server, or other antivirus clients if supported.

3.2.16 Internet

1. Only authorized Internet access from the manufacturing system network is permitted.
2. Internet access for individual devices must be approved by the Director of Operations.
3. Inbound and outbound traffic must be regulated using firewalls in the perimeter.
4. All internal and external communications must be monitored and logged. Logs must be reviewed regularly by the plant operators and reported to the Director of Operations.

3.2.17 Continuous Monitoring

1. Comprehensive network monitoring using commercial or open-source tools to detect attacks, attack indicators, and unauthorized network connections must be implemented.
2. The manufacturing system must be monitored for any cybersecurity attack indicators.
3. All external boundary network communications will be monitored.
4. All cybersecurity incidents must be logged in the incident response management system for documentation and tracking purposes.
5. All local, state, federal, regulatory, and other mandated detection activities that apply to the manufacturing system must be followed in accordance with the law, regulations, or policies.
6. Monitoring activity levels will be increased during periods of increased risk or other factors.
7. All cybersecurity incidents must be communicated to the personnel defined below:

Event Severity	List of Personnel
Low (All Events)	Control Engineers
Medium	IT Staff, Control Engineers
High (Requiring Urgent Attention)	IT Manager, Director of Operations

8. Details of cybersecurity events will be shared with ICS-CERT[15] to help secure the organization, including helping secure the industry. The Department of Homeland Security Cybersecurity and Infrastructure Security Agency (CISA) provides services for manufacturers to report cybersecurity events.

[15] https://ics-cert.us-cert.gov/

3.2.18 User Access Agreement

Each employee provided with access to any IT or OT resources (e.g., the manufacturing system, email, HR system) will be required to review and accept the terms of a User Access Agreement.

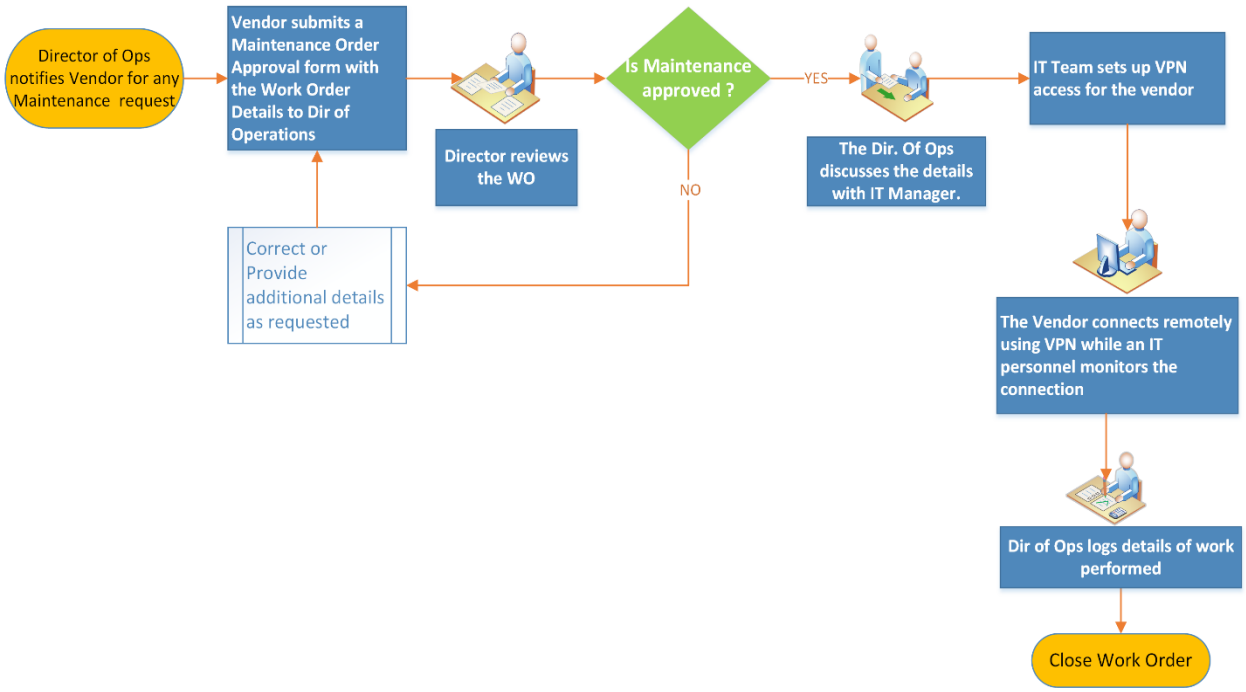
3.2.19 Remote Access

This policy applies to the users and devices that require access to manufacturing system resources from remote locations. The following rules are applicable for a one-time request.

1. All remote access requires approval by the Director of Operations. The IT Manager must also be informed. Vendors requesting remote access must be registered with the company and are required to submit all work order details using the Maintenance Order Approval Form.
2. Remote access to sensitive information is not permitted on an unencrypted connection. An exception to this rule may only be authorized in cases where it's strictly required.
3. A VPN account will be setup by the IT Team and credentials shared with the vendor. Once connected via a VPN, the vendor will be permitted Remote Desktop access to select systems such as the Engineering Workstation or HMI Server depending on the nature of the task. The access will be disabled upon completion of the work.
4. All activities will be subject to monitoring by IT staff. Monitoring will start and continue until the remote session is no longer required, or work has been completed. Appointed individuals will indicate when the remote session is active and ensure the manufacturing system environment has been returned to the same state as before the remote connection was established.
5. Installation of any software such as desktop sharing software on authorized devices will be performed by the IT staff.
6. Use of remote access technologies on personal devices is prohibited.
7. All devices connected via remote access technologies must use the most up-to-date anti-virus software and virus signatures.
8. During an onsite visit, all activities will be subject to monitoring. Dedicated IT personnel will be assigned to monitor the vendor over the shoulder while he/she is working off a computer.
9. Split tunneling will be disabled. All internet bound traffic will be directed through the corporate network during a VPN session.

3.2.20 Remote Maintenance Approval Process

Shown below is the approval process and procedure for performing remote maintenance on IT/OT assets.



3.2.21 Maintenance Approval Form

Maintenance Order Approval Form	
Vendor Name	
Vendor Address	
Vendor Phone number	
Does the Vendor provide support to Westman currently?	☐ YES ☐ NO
Does the Vendor system intended to be used have Anti-virus installed?	☐ YES ☐ NO
What items will be supported and/or worked upon during this session?	☐ PC / Laptops ☐ Servers ☐ Control System Devices ☐ Any other IT/OT Device ☐ Software Details:
Will any software or program need to be installed on Westman's systems?	☐ YES ☐ NO Details (if YES):
Does this software require licensing to be purchased?	☐ YES ☐ NO
Details of the task to be performed	
Is this a recurring activity	☐ YES ☐ NO
Vendor Signature	
Work Approved *(To be filled by Director of Operations)*	☐ YES ☐ NO
Director of Operations Signature	

3.2.22 Acronyms

Acronym	Definition
AV	Anti-virus
CEO	Chief Executive Officer
CISA	Cybersecurity and Infrastructure Security Agency
DHS	Department of Homeland Security
HMI	Human Machine Interface
HR	Human Resources
ICS	Industrial Control System
ICS-CERT	Industrial Control Systems Cyber Emergency Response Team
ID	Physical or Logical identification (e.g., badge, login name, etc.)
INFOSEC	Information Security
ISA	International Society of Automation
IT	Information Technology
NCCIC	National Cybersecurity and Communications Integration Center
NDA	Non-Disclosure Agreement
OSHA	Occupational Safety and Health Administration
OT	Operational Technology
PLC	Programmable Logic Controller
PPD	Presidential Policy Directive
SCADA	Supervisory Control and Data Acquisition
UPS	Uninterruptible Power Supply
USB	Universal Serial Bus
VPN	Virtual Private Network

3.2.23 Definitions

Term	Definition
Access Management	The practices, policies, procedures, data, metadata, and technical and administrative mechanisms used to manage access to the resources of an organization
Asset	A device owned by the organization
AV scanning	The act of scanning a device for viruses
Device	Electronic hardware (e.g., machine, computer, laptop, phone, networking equipment)
Employee	An individual directly employed by the organization
External personnel	An individual who is not an employee (e.g., contractor, visitor)
Human machine interface (HMI)	Asset used by personnel to interface and interact with OT (e.g., machines)
Industrial control system (ICS)	Typically, the hardware and software used to control processes, or operate machines and manufacturing processes

Term	Definition
Information technology (IT)	Information Technology which includes devices such as servers, laptops, workstations, switches and routers.
Least privilege	A user is only authorized to perform the functions necessary to perform their job
Operating system	Software that operates a device (e.g., Windows, Linux); typically, the interface used by the user
Operational technology (OT)	Operational Technology which includes Industrial control system devices that are used by the manufacturing process.
Personal device	A device owned by an individual; not owned or controlled by the organization
Personnel	All employees and external personnel, excluding visitors
Portable media	USB flash drive, compact disc (CD), external hard drive, laptop
Remote access technologies	Software used to connect a device to the IT or OT network via the Internet, usually performed by personnel located off-site
Security tools	
Sensitive Information	Data containing customer, personnel, proprietary, or trade secrets information pertaining to the operations of the organization; data that could cause damage to the organization if obtained by an attacker
Split tunneling	The process of allowing a remote user or device to establish a non-remote connection with a system and simultaneously communicate via some other connection to a resource in an external network. This method of network access enables a user to access remote devices (e.g., a networked printer) at the same time as accessing uncontrolled networks. [NIST SP 800-171 R1]
User	Individual using a device
Virus signature	Data used by antivirus software to identify viruses
Vulnerability	A weakness or a flaw in the system which an attacker can exploit to gain access.
Vulnerability scanning	Software used to detect common or known vulnerabilities on a device

3.2.24 Additional Resources

1. Security Policies by SANS Resources[16]
2. Template for Security Policy by Project Management Docs[17]
3. Data Security Policy by Sophos labs[18]

[16] https://www.sans.org/security-resources/policies
[17] http://www.projectmanagementdocs.com/template/Security-Policy.doc
[18] https://www.sophos.com/en-us/medialibrary/PDFs/other/sophos-example-data-security-policies-na.pdf?la=en

3.3 Cybersecurity Operations Document Example

This section provides example content that a Cybersecurity Operations document may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

Cybersecurity Operations

for

Westman

Document Owner:	Director of Operations

Version

Version	Date	Description	Author
1.0	02-22-2018	Initial Draft	Director of Operations
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Approval

(By signing below, approvers agree to all terms and conditions outlined in this document.)

Approvers	Role	Signed	Approval Date
S. Forthright	CEO	<digital signature>	4-22-2018

3.3.1 Introduction

This document defines the operational steps management and employees will follow ensuring consistence with response to events occurring within the manufacturing system for Westman. This document contains content which should be referred to often to help ensure all employees and individuals performing work within the manufacturing system are familiar with cybersecurity operations.

3.3.2 Purpose

To provide a consistent cybersecurity operational environment for supporting the manufacturing systems.

3.3.3 Scope

Management, employees, contractors, or individuals requiring access to the manufacturing system for changes should be familiar with the contents included within this document.

3.3.4 Asset Inventory

Identifying assets within the manufacturing system is a vital first step in protecting the company from malicious activities that could result in disruption to production. Additionally, knowing what devices are authorized to connect to the network enables the detection of unapproved devices which could be an indication of malicious activity. Similarly, tracking software installed on networked devices provides the necessary information to support software update and patching processes to eliminate vulnerabilities. Westman uses both manual and automated asset inventory tools to support asset inventory management. Specifically, two types of asset inventories are performed on the manufacturing system:

- Manual Inventory - Devices that cannot be automatically scanned (e.g., PLC, machining stations). These devices are manually entered into an excel spreadsheet and updated at least quarterly.
- Automated Inventory - Devices that can be automatically scanned will be configured in the asset inventory tool for auditing (i.e., Open-AudIT). Access to Open-AudIT is granted only to authorized personnel.

All inventory processes are conducted during manufacturing system down time and must include both hardware and software. Periodic hardware and software scans are performed on devices within the manufacturing system to detect any unauthorized hardware or software changes. Examples of changes that might occur within the manufacturing system include updating software, license, system patches, firmware updates, and adding new devices like PLCs' or HMIs' or other ICS components required for operations. To detect these changes within the manufacturing system, scans are conducted at least quarterly to record current device information, configuration, and installed software (e.g., license information, software version, and configuration). These scan results are used to identify any unauthorized hardware and non-essential software applications installed on devices within the manufacturing system.

Additionally, device configuration baselines are used to ensure inadvertent changes are detected before system integrity impacts can affect the manufacturing process. Both manual and automated methods are used to capture current device configurations for validation against approved baselines. The manual method is used for ICS devices that do not support automated scanning tools. Specifically, devices lacking SSH, SNMP, WMI services are manually documented in the excel spreadsheet. Automated device configuration scans are implemented using Open-AudIT which was selected for Westman due to scalable configuration depending on required needs.

Once scanning has been performed, the information gathered is compared to approved baselines with any identified changes documented for review and investigation. Any hardware or software identified within the manufacturing system that is not authorized or required for operations is scheduled for removal at the earliest opportunity that does not impact the manufacturing process. Otherwise, for any identified changes, if the change is approved, the associated baseline is updated to reflect the approved change. If the change is not approved, the device is reverted to the approved configuration and an investigation into how the unauthorized change was deployed is performed to determine if a cybersecurity incident occurred.

Device configuration baselines must be reviewed at least quarterly and updated after any approved engineering change to the manufacturing system. During the period between baseline reviews, any new equipment added or configuration changes implemented will initiate a new baseline scan to be performed. Additionally, GRASSMARLIN[19] and Wireshark[20] are used for updating the environment network diagrams, verifying information flows, and providing any additional information for supporting baseline updates after new equipment is added to the environment.

3.3.5 Networking

The Westman network environment for supporting manufacturing must be secured from unauthorized access and tampering to ensure the availability, integrity, and confidentiality of the information used to support the manufacturing processes. This requires all network connection with manufacturing system components be documented and cables clearly labeled to indicate their designated purpose. Additionally, all network switches must be configured for supporting network segmentation and port security, to control network traffic and prevent unauthorized devices from accessing the manufacturing network. Any network connection with the manufacturing environment will be reviewed and authorized by the Director of Operations before being placed into production.

To assist with these efforts, Westman creates and maintains a comprehensive network baseline that provides an accurate document of the network environment and supports the processes to detect anomalies within the manufacturing system networks. The network baseline documentation is reviewed and updated at least quarterly to identify all components and communications required for manufacturing production operations. Tools used for this process include Open-AudIT, GRASSMARLIN, and Wireshark. Additionally, using company provided network diagram tools, the network baseline documentation will include detailed network diagrams for all internal and external network connection including any cloud services. Specifically, network diagrams will include all relevant information for connection services provided including: assigned IP address for devices, service provided, data flow directions, data types, support phone number, customer number, contact person, support level agreement, and hours of support. The network baseline documentation will also include the configuration details for network segmentation and port security within the environment.

[19] https://github.com/nsacyber/GRASSMARLIN
[20] https://www.wireshark.org

The Westman network for manufacturing systems is segmented to improve speed and cybersecurity within the environment. Network traffic between network segments is controlled using firewall network devices configured, based on the approved network baseline, to allow approved network traffic to enter or leave the manufacturing network segments while dropping all other traffic. The details associated with the network segmentation, firewalls, and firewall rules is also included in the network baseline documentation.

The Westman network for manufacturing systems also utilizes managed switches that are configured with port security enabled. Port security provides the ability to allow authorized devices, based on their unique Media Access Control (MAC) addresses, to utilize specific network switch ports. The port security documentation will include a reference to the asset information for the approved devices and list device MAC addresses with the assigned network switch and switch port.

Should Westman require vendor or contractor remote maintenance support, these activities will be coordinated and approved before remote access is allowed. All remote maintenance activities will be controlled and monitored by a knowledgeable Westman employee to ensure no harmful or malicious activities occur. Any vendors or contractors connecting to Westman for remote maintenance will: require approval from the Director of Operations before connecting; utilize the approved secure remote access procedures; and have the remote access revoked after completing the approved task(s). All remote access maintenance activities will be documented to ensure a proper audit trail for activity conducted within the manufacturing systems.

All network devices will be configured to forward logs to the Westman internal Syslog server. For the Westman network for manufacturing systems, this includes the network switches, the Cisco Adaptive Security Appliance (ASA) firewall supporting the Cybersecurity LAN network, and the Stratix 8300 series firewall in the workcell.

At least monthly, authorized Westman personnel will use the information collected from these devices and the GRASSMARLIN tool to perform comparisons of current network activity to the documented baseline. These efforts will help identify any unusual traffic which might indicate either system issues or potential malicious activity. Additionally, switch logs will be checked at least monthly to ensure no rogue devices have attempted to connect. Any observed network activity not already documented in the baseline must be reconciled and either incorporated into the baseline or investigated as a possible system or cybersecurity incident.

Additionally, authorized Westman personnel will utilize a wireless enabled laptop or mobile device configured to use either the native capabilities of the operating system or approved wireless scanning software to perform weekly sweeps within the manufacturing areas to detect for unauthorized wireless devices or rogue access points. Any detected anomalies will be documented including location(s) of detection and submitted for additional investigation.

3.3.6 Manufacturing System Security

Adherence to the Cybersecurity Program by all personnel is critical to reduce the risk of cybersecurity incidents on the manufacturing system. The following sections describe policies and procedures relating to manufacturing system security.

3.3.6.1 Change Control

Any changes to the manufacturing system must be tracked by the change control process, ensuring that all personnel are notified of the proposed changes and are involved in the process. Changes will be formally reviewed and authorized before implementation.

A thorough review of the change must be performed to determine if:

- the change will impact manufacturing system performance, or
- the change will impact the security of the manufacturing system.

Change control reviewers will make a final determination before any changes are performed, along with justifications for accepted risks.

Approved changes will be scheduled during downtime or other maintenance activities to limit impact to production. Once changes have been completed, a security review will be conducted to determine if any unexpected changes to cybersecurity controls occurred as a result of the changes implemented. Any unexpected cybersecurity control changes are reviewed and processed in accordance with the Vulnerability and Remediation Management processes.

The manufacturing system will be evaluated quarterly to identify devices that are critical to its operation. This information will be used to provide a criticality report outlining the critical equipment and will be used to update other company cybersecurity documents and procedures.

Below is a table of devices that must be part of the change control process:

Device Name	Item Type	Details
Engineering Workstation	Software	BIOS/Firmware patches, IT programs (Antivirus, Backup agent etc.), Plant apps (Factory Talk, RSLinx etc.)
	Hardware	Storage and Memory upgrade
OPC Server	Software	BIOS/Firmware patches, IT programs (Antivirus, Backup agent etc.), Plant apps (PI, FactoryTalk Services Platform, RSLINX, Matrikon OPC)
	Hardware	Storage and Memory upgrade
Historian VM	Software	BIOS/Firmware patches, IT programs (Antivirus, Backup agent etc.), SQL Server patches,
	Hardware	Storage and Memory upgrade
Plant Simulator	Software	BIOS/Firmware patches, IT programs (Antivirus, Backup agent etc.)
	Hardware	Storage and Memory upgrade
Controller Host	Software	BIOS/Firmware patches, IT programs (Antivirus, Backup agent etc.), Plant apps (MATLAB, Matrikon OPC)
	Hardware	Storage and Memory upgrade
HMI Host	Software	OS Patches (Windows), BIOS/Firmware patches, IT programs (Antivirus, Backup agent etc.), Plant apps (FactoryTalk View Site, FT Services Platform, FT View Studio)
	Hardware	Storage and Memory upgrade
PLC	Software	Firmware upgrade and any type of configuration change
Allen Bradley Boundary Router	Software	Firmware upgrade, Firewall rules and any type of configuration change
Allen Bradley Layer-2 Switches	Software	Firmware upgrade and any type of configuration change
Cisco ASA Firewall	Software	Firmware upgrade, Firewall rules and any type of configuration change
Switches	Software	Firmware upgrade and any type of configuration change
Active Directory	Software	Group Policy deployment, User account creation/modification
Symantec Antivirus	Software	Antivirus version upgrades, Any Endpoint policy deployment via Symantec Manager
Nessus	Software	Running vulnerability scan(s)

3.3.6.2 Personnel Actions

Actions performed on manufacturing system devices may require authentication. Those actions are defined in the following tables. The term *All Users* only applies to users that have been granted authorization to interact with the device.

Authentication Required to Physically/Logically Interact with Device?								
	Engineering Workstation	**Supervisory PLC**	**HMI**	**Controller**	**Local Historian**	**OPC Server**	**VLAN switches**	**Boundary router**
Physical Interaction (All Users)	Y	N	N	Y	Y	Y	Y	Y
Logical/Network Interaction (All Users)	Y	Y	Y	Y	Y	Y	Y	Y

HMI User Actions Requiring Authentication			
	View Process Status	**Modify Process Setpoints**	**Silence/Clear Alarms**
All Users	N	Y	Y

Engineering Workstation User Actions Requiring Authentication				
	Login to Workstation	**View/Modify PLC Logic**	**Access Engineering Files**	**All Other Actions**
All Users	Y	Y	Y	Y

Historian User Actions Requiring Authentication				
	View Historical Data	**Modify Historical Data**	**Modify Configuration**	**Login to Server Desktop/CLI**
All Users	Y	Y	Y	Y

OPC Server User Actions Requiring Authentication		
	Modify Configuration	**Login to Desktop/CLI**
All Users	Y	Y

Controller User Actions Requiring Authentication			
	Modify Configuration	**Login to Desktop/CLI**	**Modify Control Logic**
All Users	Y	Y	Y

VLAN switches User Actions Requiring Authentication		
	Modify Configuration	**View switch status**
All Users	Y	Y

PLC Actions Requiring Authentication					
	Power On/Off	**Reboot**	**Process Interaction (Run/Stop/Reset)**	**Modify Logic**	**Change Mode (Run/Config)**
All Users	N	N	N	Y	Y

3.3.6.3 Monitoring the Manufacturing System

The manufacturing system environment will be monitored for unauthorized activity associated with personnel, software, network devices, and wireless access points. Westman has established a central log server (Syslog Server) for supporting this capability and is configured to aggregate all system-generated logs and store the logs for archival and forensics purposes. Whenever supported, devices within the manufacturing system must be configured to send log data to the central syslog repository.

Logs will be checked periodically looking for abnormal alerts being generated from the manufacturing system. Specifically, logged events will be examined to determine if any impact the manufacturing process. At a minimum, detected cybersecurity event notification will be investigated to determine root cause and appropriate remediation steps will be taken to clear events and return the manufacturing system to a known good operating state. Events impacting the manufacturing process will be reviewed to determine correlation with risk assessment outcomes and identify actions required to improve Westman's cybersecurity posture.

All non-employees physically accessing the manufacturing system will be required to sign the visitor log, including the date, time of entry, and time of exit. Any unauthorized visitors will be escorted out of the facility. Visitors must always be escorted by an employee of Westman.

3.3.6.4 Backups

The following backup procedures are defined for servers and hosts of the manufacturing system:

- Veeam directory backups are performed on select directories containing configuration and logic data for the manufacturing system are performed weekly during periods of low volume production (e.g., overnight).
- Veeam full system image backups are performed quarterly during periods of low volume production (e.g., overnight), and after any engineering change.

Host	Veeam Directory Backups	Veeam Full System Image	Other Methods
Engineering Workstation	✓	✓	
OPC Server		✓	
Process Controller Server		✓	
HMI Host Server		✓	
Local Historian Host		✓	OSIsoft PI historian data of the manufacturing process is duplicated in real-time to the DMZ Historian.
Hyper-V Host Server		✓	
Active Directory Server		✓	
Backup Active Directory Server		✓	
DMZ Historian		✓	The native OSIsoft PI application backup feature archives production data from the manufacturing process. These backups are stored on the local host; restore the host to obtain the most recent backup version. NOTE: Any recovered historical data will be limited to data present at the time of the backup.
Symantec Antivirus Server		✓	
Security Onion Server		✓	
Graylog Server		✓	

GTB Inspector Server		✓	
GTB Console Server		✓	
The Hive Project Incident Response Server		✓	
Nessus Vulnerability Scanner Server		✓	
Windows WSUS Server		✓	

The following backup methods described are for hosts and devices that cannot be performed by the Veeam tool.

Host	Backup Methods
Local Historian Database Virtual Machine	Backup of the VHD is handled by the Veeam full system image of the host server, Local Historian Host (FGS-61338LHH).
Controller PLC	Backup of the PLC project files is handled by the Veeam full system image of the Engineering Workstation (FGS-47631EHH), as the files are stored locally on that host.
	Veeam full image backups of Engineering Workstation (FGS-47631EHH) must be manually performed after any engineering changes to the PLC project or its configuration.
	Backup of the SD card contents is performed annually during the plant shutdown.
Manufacturing System Router / Firewall	Perform a configuration backup via the CLI or web UI after any engineering change.
Boundary Router	Perform a configuration backup via the CLI or web UI after any engineering change.
Supervisory LAN Switch	Perform a configuration backup via the CLI or web UI after any engineering change.
Control LAN Switch	Perform a configuration backup via the CLI or web UI after any engineering change.
VMware Host	Perform regular backups of each running Virtual Machine hosted on VMWware ESXi using Veeam.
	Perform a backup of the ESXi Host configuration after any configuration changes. (see VMWare KB[21] for additional details).

[21] https://kb.vmware.com/s/article/2042141

3.3.6.5 Media Sanitization

Storage media (e.g., flash memory, memory cards, hard drives) must be sanitized before disposal or removal from the facility. Sanitization procedures for manufacturing system devices are described below.

Assets / Device type	Details
Hard drives on servers, workstations	Tool: DBAN[22] Procedure: 1. Download and create a bootable media of DBAN. 2. Boot the server using the bootable media. 3. Follow the on-screen instructions to run the multiple passes of data wipe. 4. Once complete, verify if wipe was successful by booting the server without the DBAN media.
Allen Bradley 8300 Boundary Router	The instructions below are found in the Allen Bradley manual for Stratix Managed Switches[23]. Procedure: 1. Login to Web Admin console. 2. Navigate to **Device Management** > **Restart/Reset** in the menu. 3. Select **Reset Switch to Factory Defaults** and click on **Submit**.
Allen Bradley 5700 L2 switch	The instructions below are found in the Allen Bradley manual for Stratix Managed Switches[23]. Procedure: 1. Login to Web Admin console. 2. Navigate to **Device Management** > **Restart/Reset** in the menu. 3. Select **Reset Switch to Factory Defaults** and click on **Submit**.
HMI	The HMI program is installed on a Windows 7 system. To uninstall this program 1. Login to the Windows system via an admin account. 2. Select **Control Panel** > **Programs and Features**. 3. Select and Uninstall all "**FactoryTalk**" components. 4. Reboot the machine, if required.
Allen Bradley PLC	The Allen Bradley PLC consists of three modules: • DeviceNet Scanner, • ControlLogix Module, and • HIPROM time. To reset the HIPROM Time Module[24]: 1. Set the rotary switches to 888. 2. Power up the module.

[22] https://www.dban.org
[23] http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf
[24] http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1756-um538_-en-p.pdf

	To reset the DeviceNet Scanner Module[25]: 1. Set the rotary switches to 888. 2. Power on the module. Instructions for clearing the memory in the ControlLogix 5571 module are defined in the Allen Bradley ControlLogix 5000 Manual[26]. 1. Remove the ESM from the controller. 2. Remove power from the controller. 3. Remove power either by: a. turning power off to the chassis while the controller is installed in the chassis, or b. removing the controller from the powered chassis. 4. Reinstall the ESM into the controller. 5. Restore power to the controller.

3.3.6.6 Resources are Maintained

Resource performance can impact manufacturing process performance. Operators must perform daily checks on the manufacturing system components they operate or are responsible for. These checks must include physical observation of all components, and review of any warning messages or indicators, and any other areas of concern designated by the Director of Operations.

3.3.7 Personnel Training

Training is vital for keeping the company safe from cybersecurity threats. All employees, contractors and vendors must complete required annual cybersecurity training before being allowed to work or continue working within the manufacturing system environment. Individuals with privileged access are required to complete additional training identified by the Director of Operations or the IT Manager related to managing the cybersecurity controls and configurations for the devices they are granted privileged access rights.

3.3.8 Vulnerability Management

Vulnerability management is an essential component of any information security program and the process of vulnerability assessment is vital to effective vulnerability management.

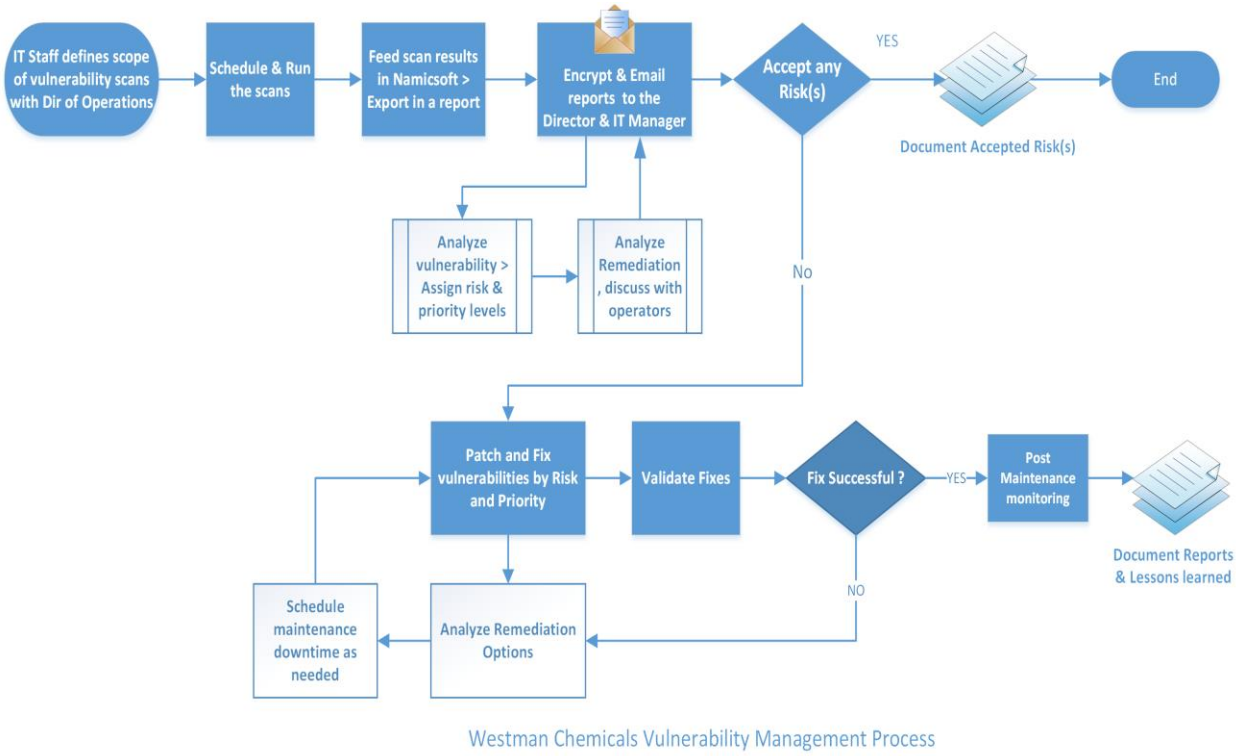
The following general policies apply to vulnerability management:

- The Engineers or IT staff will not make any temporary changes to information systems, for the sole purpose of "passing" an assessment. Vulnerabilities on information systems shall be mitigated and eliminated through proper analyses and repair methodologies.

[25] http://literature.rockwellautomation.com/idc/groups/literature/documents/in/1756-in566_-en-p.pdf
[26] http://literature.rockwellautomation.com/idc/groups/literature/documents/um/1756-um001_-en-p.pdf

- No devices connected to the network shall be specifically configured to block vulnerability scans from authorized scanning engines.
- Use caution when running vulnerability scans against OT networks such as the Supervisory LAN and Field LAN Network. Scans should be scheduled off hours and during periods of maintenance.
- It is recommended to run authenticated scans from the vulnerability scanner.

3.3.8.1 Vulnerability Management Process



Westman Chemicals Vulnerability Management Process

3.3.8.2 Vulnerability Scanning and Management Tools

Tenable-Nessus is being used to perform vulnerability scans in Westman. The results generated by Nessus at the completion of the scan are imported into NamicSoft, a vulnerability management, parsing and reporting tool. NamicSoft is used to create customized reports and logically group results for a consistent workflow within the organization. The reports are reviewed by the Director of Operations and the IT Manager and shared with IT staff members as required to coordinate remediation or mitigation activities.

3.3.8.3 Vulnerability Scan Targets

All devices connected to the Plant and Supervisory network segments are scanned. The IT Staff will configure a scan for all network segments of Westman.

A new scan can be established, or a modification can be made to an existing scan, by submitting a request to the IT Manager.

Note: If an individual identifies that a scan is impacting the manufacturing process, they must report the situation immediately to the IT Manager to request stopping the scan and report the situation to the Director of Operations.

3.3.8.4 Vulnerability Scan Frequencies

Scans are performed by the IT Staff on an on-demand, per-request basis as needed. Due to the potential impact to manufacturing processes, scans are performed only during scheduled preventive maintenance periods. The Director of Operations and IT manager shall coordinate at least one (1) assessment per month for at least the DMZ, Cybersecurity, Management, and Engineering LAN segments provided the scans can be coordinated without impacting the manufacturing process. All network segments and devices are scanned during the annual plant shut down period.

All device scans should be performed during hours appropriate to the business needs of the organization and to minimize disruption to normal operations. Any new device discovered needs to be reported, confirmed that the device is approved, and classified under its appropriate group.

3.3.8.5 Vulnerability Reporting

Upon completion of a vulnerability scan, the result is imported into NamicSoft for report generation. The generated reports are achieved and retained as proof that an assessment occurred and for supporting trend analysis.

All IT/OT devices are organized into groups in NamicSoft as per the system they reside in. A device may belong to one or more groups. Reports are generated for the entire system so that the devices and vulnerabilities can be easily presented to the IT Staff, IT Manager and Director of Operations. Below is a table of type of reports that are generated and disseminated.

Status Reports	Frequency	Purpose
Host table with affected vulnerabilities	Monthly	Information is presented for each host.
Vulnerability Assessment Report	Monthly	Information is presented for both scanned networks.
Host specific report	Ad-hoc	Information is presented for requested host.
Mitigated vulnerabilities report	Post remediation	Upon re-scanning a host to check if vulnerabilities have been mitigated or not

3.3.9 Remediation Management and Priorities

All vulnerabilities discovered must be analyzed by the Director of Operations and the IT Manager with assistance from control engineers and OT service contractor (if needed) to decide the next course of action.

All vulnerabilities discovered should be remediated within the remediation times defined in the following table.

Severity	Description	Remediation time
Critical	Nessus uses Common Vulnerability Scoring System (CVSS) for rating vulnerabilities. A Critical vulnerability has a CVSS base score of 9.0 or 10.	Within 15 days of discovery
High	High-severity vulnerabilities have a CVSS score between 7.0 and 8.9.	Within 30 days of discovery
Medium	Medium-severity vulnerabilities have a CVSS score of 4.0 to 6.9 and can be mitigated within an extended time frame.	Within 45 days of discovery
Low	Low-severity vulnerabilities are defined with a CVSS score of 1.0 to 3.9. Not all low vulnerabilities can be mitigated easily due to applications and normal operating system operations. These should be documented	Within 180 days of discovery
Info	Info level do not present cybersecurity risk and are listed for informational purposes only. It is optional to remediate them.	Not required to remediate

3.3.9.1 Exception Management

Exceptions are sometimes required as part of the organizational risk management process to ensure regulatory, cybersecurity, and manufacturing priorities are properly aligned to create a cost-effective cybersecurity environment for supporting the manufacturing systems. There are two primary use cases associated with exception requests: false positives – vulnerabilities identified incorrectly or that are not actually present within the identified system; and risk acceptance – risks that cannot be avoided, mitigated, or transferred.

False Positives exceptions must be documented and approved by the Director of Operations. Approved false positives will be submitted to the IT Staff who will update scanning and reporting to exclude the false positive results from future reports.

Risk acceptances are necessary to address vulnerabilities that may exist in operating systems, applications, web applications or OT devices that cannot be remediated, or otherwise avoided. For example, vendors may have appliances that are not patched, services may be exposed for proper application operations, and systems may still be commissioned that are considered end-of-life by the developer and manufacturer. Exceptions may also be requested for vulnerabilities not identified as risks to the system and organization (e.g., if a patchable vulnerability is only exploitable by a user utilizing a web browser and accessing a compromised website, then a risk acceptance exception to the patch that has an identified impact on the manufacturing process could be considered given the mitigations of blocking internet access from the manufacturing network segments).

Risk acceptance exceptions must be requested through the IT Team with an explanation containing:

- Mitigating controls: what changes, tools, or procedures have been implemented to minimize the risk.
- Risk acceptance explanation: details as to why this risk is not relevant to the company and systems.
- Risk analysis: if the vulnerability is indeed compromised, what risk and systems will be affected.

Any other exceptions to this policy, such as exemption from the vulnerability assessment process must be internally discussed and approved by the Director of Operations.

3.4 Risk Management Document Example

This section provides example content that a Risk Management document may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

Risk Management Strategy

for

Westman

Document Owner:	Director of Operations

Version

Version	Date	Description	Author
1.0	02-22-2018	Initial Draft	Director of Operations
2.0	04-21-2018	Major changes to the initial draft	Director of Operations

Approval

(By signing below, approvers agree to all terms and conditions outlined in this document.)

Approvers	Role	Signed	Approval Date
S. Forthright	CEO	<digital signature>	4-22-2018

This Risk Management Plan defines how cybersecurity risks associated with the Westman manufacturing systems will be identified, analyzed, and managed. This document can be used by the Director of Operations and senior management to foresee risks, estimate impacts, and define responses.

3.4.1 Scope

Any employee, contractor, or individual with access to the organization's systems or data.

3.4.2 Risk Management Process

Risk Management is an iterative process. As the program progresses, more information will be gained about the program, and the risk statement will be adjusted to reflect the current understanding. The overall process involves Identifying, Analysis, Categorizing, Remediating, and Reporting. A Risk Management Log is maintained to track known risks and remediation efforts.

3.4.3 Identification

Risks will be identified as early as possible in the project to minimize their impact. For the purposes of this process, risks are threats exploiting vulnerabilities or weaknesses in technology, processes, or policy that may cause an adverse impact or harm to the organizational operations, organizational assets, or individuals.

There are many different types of threats that can affect IT and OT infrastructure. Common threat sources (adapted from NIST SP 800-30[27]) include:

- **Adversarial** — individuals, groups, organizations, or states that seek to exploit the organization's dependence on cyber resources.
- **Accidental** — Erroneous actions taken by individuals in the course of executing their everyday responsibility
- **Structural** — Failure of equipment, environmental controls, or software due to gaining, resource depletion, or other circumstances which exceed expected operating parameters.
- **Environmental** — Natural disasters and failures of critical infrastructures on which the organization depends, but which are outside the control of the organization.

The Director of Operations and IT Team will coordinate the formal manufacturing system annual risk assessments in accordance with the latest version of the NIST SP 800-30[28] guidance. During this process, specific organizational threat events will be identified and defined for use in assessing vulnerabilities and weaknesses to determine if a risk exists.

For continuous monitoring and risk management, Westman's employees or external contractors must report any potential risk following the risk notification process described below. Additionally, software tools including, but not limited to, Nessus and CSET[29] are used to support the risk assessment process by identifying vulnerabilities and weaknesses in the technology, processes, or policies for the organization.

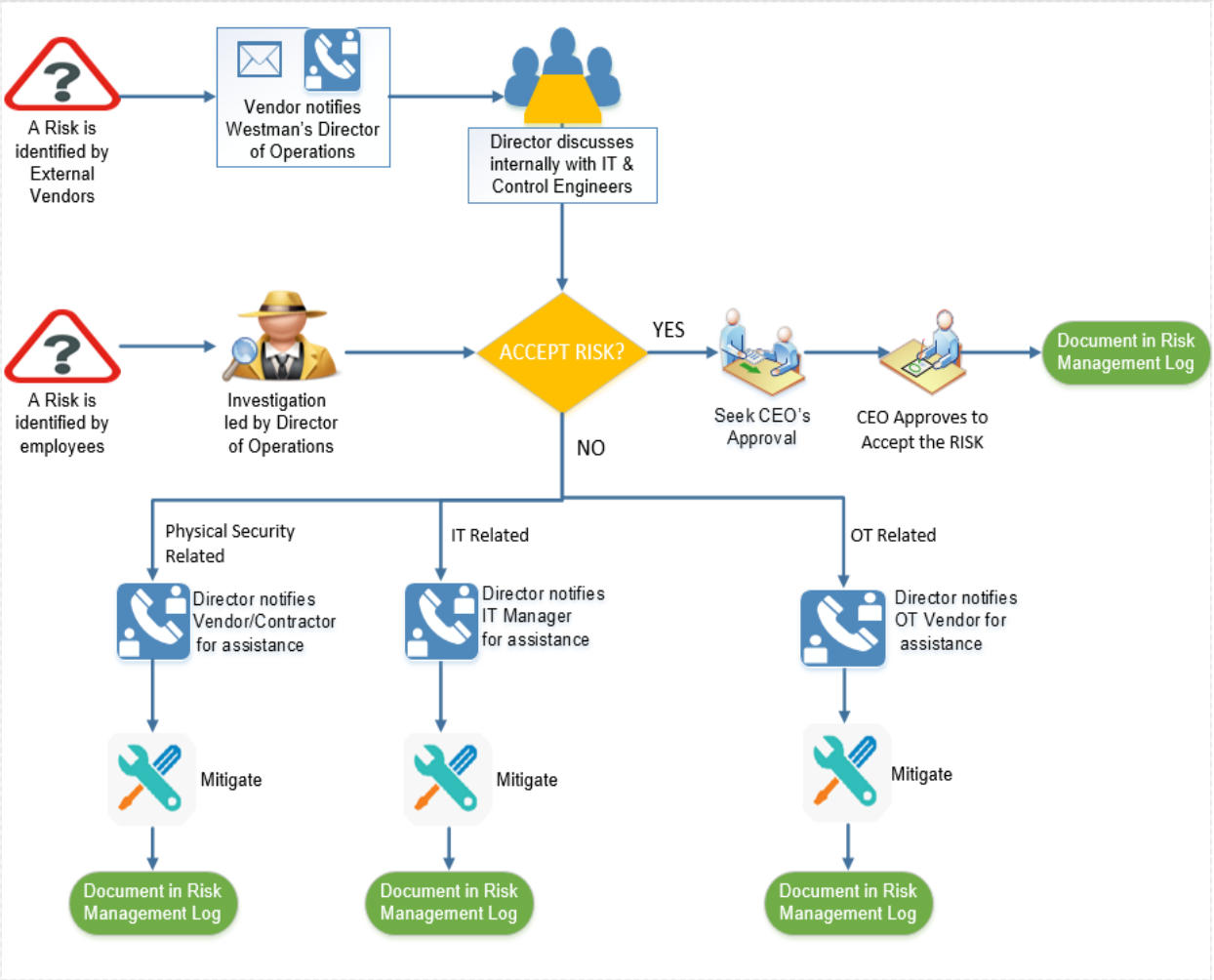
The Director of Operations will perform a CSET assessment at least annually. Due to the potential impact to manufacturing processes, scans are performed only during scheduled preventive maintenance periods. Nessus results will be imported into NamicSoft and reports generated and distributed to the Director of Operations and the IT Manager. Additionally, other

[27] https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-30.pdf
[28] https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-30.pdf
[29] https://ics-cert.us-cert.gov/Assessments

types of risks, such as hardware based, physical, or environmental will be identified and documented manually.

Note: Any software-based vulnerabilities that cannot be remediated per the Vulnerability Management Plan will be included in the risk analysis process to determine the appropriate corrective action.

Risk Notification Process



3.4.4 Analysis

To begin the analysis process, each vulnerability must be assigned a vulnerability score from 1 to 10. Vulnerabilities identify by CSET will be manually assigned a score from 1 to 10 based on the severity of the finding by the assessor. For vulnerabilities identified through scanning tools such as Nessus, the CVSS associated with the vulnerability will be used as the vulnerability score.

At a minimum, vulnerabilities with a score in at the high (vulnerability score: 7.0 to 8.9) and critical (vulnerability score of 9.0 to 10) range will be analyzed to determine if an associated

threat or threat event exists that has a probability of occurrence greater than zero. For each vulnerability, threat pairs, an impact on operations will be estimated. A qualitative risk analysis process will be used to determine the overall probability and impact levels using the guidance in the tables below. These factors are then combined to provide an estimated quantitative risk score for use in reporting and prioritization.

Probability	Description	Quantitative Value
High	Greater than <70 %> probability of occurrence in a year	0.8
Medium	Between <30 %> and <70 %> probability of occurrence in a year	0.5
Low	Below <30 %> probability of occurrence in a year	0.3

Note: At the discretion of the assessor or the Director of Operations, the probability quantitative value may be adjusted to more accurately represent the probability of occurrence up to a maximum of 1 representing 100 % probability of occurrence and to a minimum of 0 representing 0 % probability due to no identified threat or threat event being identified for the vulnerability or weakness.

Impact	Description	Quantitative Value
High	Risk that has the potential to seriously impact production cost, production schedule or performance	1
Medium	Risk that has the potential to moderately impact production cost, production schedule or performance	0.5
Low	Risk that has relatively minor impact on cost, schedule or performance	0.1

Notes: Overall impact scores are the product of the qualitative level from the impact table and the asset criticality as defined below resulting in an impact range of 1-10. If an asset criticality has not been defined, then assume an asset criticality of 10 until the asset can be properly categorized.

Asset Criticality Matrix

Once a list of Westman assets or systems requiring protection have been identified by the Hardware Inventory process, they will be assigned a value. Asset Value is the degree of impact that would be caused by the unavailability, malfunctioning or destruction of the asset.

Westman will use the following scale to calculate Asset value.

Criticality	Description	Asset Value
Critical	Loss or damage of this asset would have grave / serious impact to the operations of the Manufacturing system directly impacting production. This can result in total loss of primary services, core processes or functions. These assets are single point of failure.	10
High	Loss or damage of this asset would have serious impact to the operations of the Manufacturing system directly impacting production. This can result in major loss of primary services, core processes or functions. These assets can also be single point of failure.	7 to 9
Medium	Loss or damage of this asset would have moderate impact to the operations of the Manufacturing system or Production. This can result in some loss of primary services, core processes or functions.	3 to 6
Low	Loss or damage of this asset would have minor to no impact on the Operations of the Manufacturing system or Production. This can result in little or no loss of primary services, core processes or functions.	1 to 2

A list of assets belonging to Westman with assigned value is presented in the table below.

Asset	Value	Asset Value
IT / Communication Systems	High	8
OT / Field Devices – PLC, HMI	Critical	10
Electrical Systems	Critical	10
Utility Systems	Medium	6
Site	High	8

3.4.5 Categorization

Categorization of risks begins by computing the overall risk score. The overall risk score is computed using the following equation:

Risk Score = Vulnerability Score X Probability X Impact X Asset Criticality

The resulting risk score (1 to 100) is then used for determining the overall risk level (adapted from NIST SP 800-30[30]) which is utilize for prioritizing remediation efforts.

Risk Level	Description	Risk Score
Very High	Very high risk means that the identified vulnerability could be expected to have multiple severe or catastrophic adverse effects on organizational operations, organizational assets, or individuals.	96 to 100
High	High risk means that the identified vulnerability could be expected to have a severe or catastrophic adverse effect on organizational operations, organizational assets, or individuals.	80 to 95
Medium	Moderate risk means that the identified vulnerability could be expected to have a serious adverse effect on organizational operations, organizational assets, or individuals.	21 to 79
Low	Low risk means that the identified vulnerability could be expected to have a limited adverse effect on organizational operations, organizational assets, or individuals.	5 to 20
Very Low	Very low risk means that the identified vulnerability could be expected to have a negligible adverse effect on organizational operations, organizational assets, or individuals.	0 to 4

The resulting risk information is then entered into the risk management log for tracking and for coordinating remediation.

3.4.6 Remediation

For each risk rated moderate or higher, one of the following approaches will be selected for remediation:

- **Avoid** – eliminate the threat by eliminating the cause
- **Mitigate** – Identify ways to reduce the probability or the impact of the risk
- **Accept** – accept the risk
- **Transfer** – transfer the risk by having another party responsible for the risk (buy insurance, outsourcing, etc.)

[30] https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-30.pdf

Risk mitigations and transfer efforts may require additional research and time to implement. As necessary, the Director of Operations will reach out to IT/OT Vendor for any risks and request remediation assistance. For any corrective actions taken, including risk acceptance, the risk management log must be updated.

Each risk mitigation and transfer effort will be maintained on the Risk Management log and tracked by the Director of Operation until completed. Once completed, an assessment of the implemented mitigation will be performed to assess the new residual risk level for the vulnerability and determine if the residual risk is within an acceptable range for continued operations.

Any risk acceptances must follow the process established in the Remediation Management and Priorities and Exception Management sections of the Cybersecurity Operations Document.

3.4.7 Reporting

This table describes the frequency and format of how the Director of Operations or IT Manager will document, analyze, communicate, and escalate outcomes of the risk management processes.

Reporting Method	Description	Frequency
Risk Management log	A document to report the results of risk identification, analysis, and response planning	Yearly
CSET Report	A document describing Risk assessment results	Yearly
NamicSoft report	A document containing results of Nessus vulnerability scans.	Manual/Post vulnerability assessment

The Director of Operations will share the results of risk assessments (either the Risk Management Log or CSET Report) with the CEO.

Sample Risk Management Log

The Risk Management Log will be maintained by the Director of Operations and reviewed in the monthly senior management meeting. This log captures the results of the latest risk analysis and the status of planned corrective actions.

Risk	**Category (Technical, Management, Contractual, External)**	**Probability**	**Impact**	**Risk Score**	**Risk Mitigation Strategy** (e.g. Avoid, Transfer, Mitigate or Accept the risk)	**Actions required**	**Status (Open, closed, In Progress)**	**Due Date**

3.4.8 Definition and Acronyms

IT	Information Technology which includes devices such as servers, laptops, workstations, switches and routers.
OT	Operational Technology which includes Industrial control system devices that are used by the manufacturing process.
Vulnerability	A weakness or a flaw in the system which an attacker can exploit to gain access.

3.4.9 Additional Resources

1. Risk Management plan – Maryland Department of Information Technology[31]
2. Sample Risk Management plan – State of North Dakota[32]

[31] doit.maryland.gov/SDLC/Documents/Project%20Risk%20Managment%20Plan.doc
[32] https://www.nd.gov/itd/sites/itd/files/legacy/services/pm/risk-management-plan-sample.pdf

3.5 Incident Response Plan Document Example

This section provides example content that an Incident Response Plan document may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

Incident Response Plan

for

Westman

Document Owner:	Director of Operations

Version

Version	Date	Description	Author
1.0	02-22-2018	Initial Draft	Director of Operations
2.0	04-21-2018	Major revision	Director of Operations

Approval

(By signing below, approvers agree to all terms and conditions outlined in this document.)

Approvers	Role	Signed	Approval Date
S. Forthright	CEO	<digital signature>	4-22-2018

3.5.1 Statement of Management Commitment

Westman's management team is committed to information security and appropriate incident response to accidental or deliberate cybersecurity incidents within the company. Westman has created the Incident Response Plan to establish an actionable information security incident handling capability that includes planning, detection, analysis, containment, and reporting for cybersecurity incidents.

3.5.2 Purpose and Scope

An incident can be defined as an occurrence that actually or potentially jeopardizes the availability, integrity, or confidentiality of the manufacturing system or the information the system processes, stores, or transmits or that constitutes a violation or imminent threat of violation of security policies, security procedures, or acceptable use policies. This document describes the plan for responding to cybersecurity incidents at Westman. It defines the roles and responsibilities of personnel, incident classification, the incident response workflow, and reporting requirements. The purpose of this plan is to determine the scope and risk of cybersecurity incidents, respond appropriately to the incident, communicate the incident with all stakeholders, and reduce the likelihood of future impact. This plan applies to all manufacturing system personnel, networks, systems, and data of Westman.

3.5.3 Roles and Responsibilities

The Incident Response Team is comprised of the following personnel. Personnel responsibilities are also described. Further personnel responsibilities are defined throughout this plan.

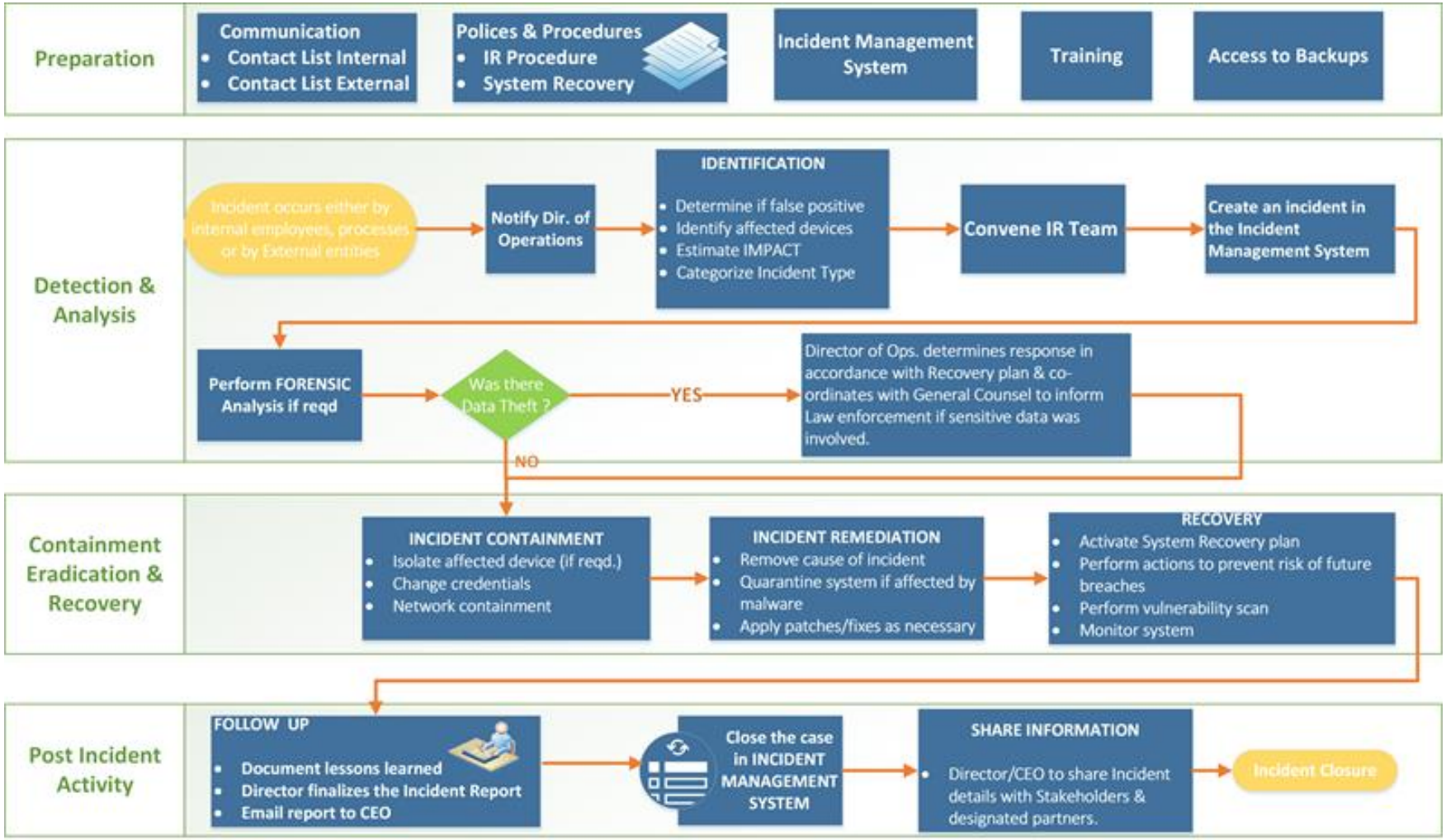
Role	Incident Response Responsibilities
Director of Operations	• Serves as a primary point of contact for any cybersecurity incident. • Ensure all employees understand how to identify and report a cybersecurity incident. • Leads the investigation for incidents, completing the Incident Report, and reporting to the CEO as required. • Documents all details of cybersecurity incidents.
Control Engineer(s)	• Reporting cybersecurity incidents, operational issues or concerns to the Director of Operations. • Assisting with incident response when this plan is activated.
IT Manager	• Assist in investigation, troubleshooting, and mitigation of cybersecurity incidents. • Advises the Director of Operations regarding procedures, policies and best practices for incident response.
General Counsel	• Handling of any legal matters or questions regarding a cybersecurity incident. • Review of external communications related to a cybersecurity incident. • Coordinate with the HR Manager to inform law enforcement if a cybersecurity incident involves a data breach of sensitive information (e.g., PII).
HR Manager	• Handling of any personnel and disciplinary issues relating to a cybersecurity incident. • Inform the Director of Operations if a cybersecurity incident involves a data breach of sensitive information (e.g., PII).

3.5.4 Policy

1. Upon notification of a cybersecurity event, the Director of Operations must determine if the Incident Response Plan should be activated based on available information from event.
2. The Director of Operations must inform all personnel listed in Section 3.5.7 of this document when the response plan has been activated.
3. Impact to the manufacturing system must be determined by thorough investigation, and an incident type and severity level assigned. The Incident Report Template form should be used for this purpose. The severity level will be assigned by the Director of Operations in consultation with the IT Manager.
4. Approval must be received from the CEO and General Counsel if additional resources (i.e., external entities) are to be contacted to assist with incident response (e.g., forensic investigators, IT consultants, cybersecurity consultants, law enforcement, etc.).
5. The Director of Operations or IT Manager must coordinate the Incident Response Plan with stakeholders.
6. User awareness, training, and testing procedures must be reviewed after every incident and updated as necessary.
7. The General Counsel should be involved throughout the incident response due to the potential for legal action arising from the incident.

3.5.5 Incident Response Workflow

The Incident Response workflow must operate as follows.



3.5.6 Internal and External Communications

The following policies are applicable to internal and external communications that are performed during an incident response:

- The CEO must identify and promptly contact primary partners, stakeholders, and customers to inform them about response activities. This should be performed once the impact of the incident is understood, and a corporate response has been prepared.
- The Director of Operations must contact all personnel responsible for system recovery, listed below, once this plan has been executed.
- The Director of Operations must establish reporting requirements on the progress of incident response activities to stakeholders.
- Communications with any external entities must be initiated by personnel explicitly authorized by this plan, or as authorized by the Director of Operations during execution of this plan.
- Approval must be received from the CEO and General Counsel before collaborating with any outside entity during an incident response.

3.5.7 Personnel Contact Information

The following table contains the contact information for critical Westman personnel who will likely be involved in the Incident Response process.

Name	Title	Contact Type	Contact Information
S. Forthright	Chief Executive Officer (CEO)	Work	301-555-0141 ext. 102
		Mobile	240-555-0159
		Alternate	301-555-3554
		Email	s.forthright@nist-westman.com
W. Lumbergh	Director of Operations	Work	301-555-0141 ext. 103
		Mobile	240-555-0110
		Alternate	301-555-3110
		Email	w.lumbergh@nist-westman.com
E. Dufresne	Control Engineer	Work	301-555-0141 ext. 110
		Mobile	240-555-0543
		Alternate	301-555-3543
		Email	e.dufresne@nist-westman.com
M. West	General Counsel	Work	301-555-0141 ext. 107
		Mobile	240-555-2173
		Alternate	301-555-3173
		Email	m.west@nist-westman.com
E. Kenmore	IT Manager	Work	301-555-0141 ext. 108
		Mobile	240-555-0824
		Alternate	301-555-3824
		Email	e.kenmore@nist-westman.com
J. Smith	HR Manager	Work	301-555-0141 ext. 109
		Mobile	240-555-0543
		Alternate	301-555-3543
		Email	j.smith@nist-westman.com

3.5.8 External Contact Information

The following table contains the contact information for external entities that may be contacted while execution of the Incident Response Plan is ongoing to support or provide relevant information to support the response process. External entities and organizations listed below must only be contacted by authorized personnel, as per the guidance described in this plan.

Name	Title	Contact Type	Contact Information
OT Contractor Cyberdyne Systems Account # 88525462A	General Support	Work	1-800-555-6543 Option 1, 3, 5
		Mobile	N/A
		Alternate	N/A
		Email	support@cyberdynesystems.com
Power Company Account # 5486548	General Support	Work	1-800-555-4343 Option 1,4,7,9
		Mobile	N/A
		Alternate	N/A
		Email	N/A
Telecom Carrier Account # 3340444	General Support	Work	1-800-555-8769
		Mobile	N/A
		Alternate	N/A
		Email	N/A
Insurance Provider Account # 8858444	Agent (R. Parr)	Work	1-800-555-7643
		Mobile	240-555-5698
		Alternate	240-555-5433
		Email	r.parr@insuricare.com

3.5.9 Information Sharing Policy

1. The Director of Operations, in collaboration with the CEO, IT Manager, and General Counsel, must promptly prepare a report detailing relevant information about the incident response, and may share the report with designated sharing partners.
2. All communications regarding information sharing about an incident or incident response to external parties must be made in consultation with the CEO.
3. The CEO, Director of Operations, IT Manager, and General Counsel must determine the relevant information about the incident to be shared.

3.5.10 Public Communications

1. Any public response must be clear, consistent, and professional.
2. The CEO and General Counsel must approve all public communications regarding a cybersecurity incident.
3. If required, an outside public relations firm may be contracted to assist in development of a response and responding to any public inquiry.
4. All communications with the media must be approved by the CEO and General Counsel.
5. The CEO, Director of Operations, or General Counsel may communicate the public response, depending on the severity of the cybersecurity incident.

3.5.11 Plan Maintenance

This plan must be reviewed and updated after:

- the plan is executed in response to a cybersecurity incident,
- the plan is executed during an incident response exercise,
- any organizational changes, or
- any modifications or maintenance to the manufacturing system or its components that may impact this plan.

The Director of Operations must update the document in consultation with Controls Engineers and other personnel, as required, and must communicate any changes or updates made to this policy to personnel responsible for its execution.

3.5.12 Plan Testing

This plan must be tested during planned downtime each calendar year. During this time, Incident Response team members must be convened to perform the following activities:

- incident response tabletop exercises,
- review of the documented procedures,
- validation of plan effectiveness,
- identification of any gaps or weaknesses in the plan execution, and
- update the plan with any outdated or missing information.

3.5.13 Incident Type Classification

Westman defines the following types of cybersecurity incidents for internal classification.

Incident Type	Description
Intrusion	A security event, or a combination of multiple security events, that constitutes a security incident in which an intruder gains, or attempts to gain, access to a system or system resource without having authorization to do so.[33]
Denial of Service (DoS)	The prevention of authorized access to a system resource or the delaying of system operations and functions.[34]
Virus or malware	Software or firmware intended to perform an unauthorized process that will have adverse impact on the confidentiality, integrity, or availability of an information system. A virus, worm, Trojan horse, or other code-based entity that infects a host. Spyware and some forms of adware are also examples of malicious code.[35]
Social engineering	An attempt to trick someone into revealing information (e.g., a password) that can be used to attack systems or networks.[36]
Data loss	The exposure of proprietary, sensitive, or classified information through either data theft or data leakage.[37]
Missing or stolen IT/OT hardware	Any manufacturing system hardware (in-use, backup, spare, or surplus) that cannot be accounted for.
User account compromise	The unauthorized disclosure, modification, or use of a user account on the manufacturing system.
System misuse	The unauthorized use of a manufacturing system component.

[33] CNSSI 4009-2015 (IETF RFC 4949 Ver 2)
[34] NIST SP 800-82 Rev. 2 under Denial of Service (DoS) (RFC 4949)
[35] NIST SP 800-82 Rev. 2 under Malware (NIST SP 800-53)
[36] NIST SP 800-82 Rev. 2 under Social Engineering (NIST SP 800-61)
[37] CNSSI 4009-2015 (NIST SP 800-137)

3.5.14 Incident Severity Classification

The severity of a cybersecurity incident is determined based on the impact to manufacturing operations, the information impact, the potential for future operational or information impacts, and the recoverability. The table below describes the classification levels for incident severity, and their classifiers.

Severity	Classifiers
High	• All users of the company are impacted. • One or more of the mission objectives are severely impacted (e.g., production impact or stoppage). • Sensitive information loss (i.e., data breach). • There is no temporary operational procedure to maintain or restore manufacturing system production. • Recoverability is unpredictable, additional resources and outside help are required, or recovery is not possible. [38]
Moderate	• One or more of the mission objectives are impacted. • There are temporary operational procedures that can be implemented to maintain or restore manufacturing system production. • Service interruption potentially affects specific users and does not involve sensitive or personal data breach. • Non-sensitive information loss (i.e., data breach). • Recoverability is predictable with existing or additional resources. [38]
Low	• No impact to mission objectives. • Service interruption potentially affects only one user and does not involve sensitive information loss. • Recoverability is predictable with existing resources. [38]

[38] NIST SP 800-61 Rev. 2

3.5.15 Incident Report Form Template

Incident Reporting Form [39,40]		
Contact Information		
Date:		Time:
Name:	Title:	Dept:
Office Phone:		
Incident Details		
Incident Date:		Incident Time:
Type of Incident - Check all that apply		
☐ Intrusion	☐ System Misuse	☐ Social Engineering
☐ Denial of Service	☐ Data Breach	☐ User Account Compromise
☐ Virus / Malware	☐ Hardware Stolen	☐ Other
Description of Incident:		
Impact or Potential Impact - Check All that Apply		
☐ Loss or Compromise of Data	☐ Financial Loss	
☐ Damage to Systems	☐ Other Organizations Affected	
☐ Damage to Public	☐ Damage to Integrity or Production	
☐ System Downtime	☐ Unknown at this time	
Description of Impact:		

[39] Pennsylvania Department of Human Services, http://www.dhs.pa.gov/cs/groups/webcontent/documents/form/p_031584.doc
[40] AHIMA BOK, https://bok.ahima.org/doc?oid=76732

Incident Reporting Form (cont.)			
Affected Systems			
Host	**IP Address**	**Applications (if any)**	**Operating System**

Scope of Data Loss (if any)
☐ Public - Data previously approved for release or is publicly available.
☐ Internal Use - Data intended for internal company use, other affiliated organizations, or business partners. Unauthorized disclosure may be against laws or regulations and may cause harm the company or its business partners or its customers.
☐ Sensitive - Private, proprietary, customer, or trade secret data. Restricted to those with legitimate business need for access. Unauthorized disclosure is against laws or regulations, and will likely harm the company, its business partners, or customers (e.g., trade secrets, source code, personnel data, PII).

Data Loss Details
Description of Data Loss:

Follow Up Actions Initiated	
☐ Law Enforcement Notified	☐ System Removal from Network
☐ Restored from Backups	☐ Log Files Examined
☐ AV Definitions Updated	☐ No Actions
☐ System Reimage or Quarantine	☐ Other
Description of Actions Initiated:	

Director of Operations Sign-Off		
Name:	Signature:	Date:

3.5.16 Acronyms

Acronym	Definition
CEO	Chief Executive Officer
CNSSI	Committee on National Security Systems Instruction
DMZ	Demilitarized Zone
DOS	Denial of Service
HR	Human Resources
IRP	Incident Response Plan
IT	Information Technology
LAN	Local Area Network
NIST SP	National Institute of Standards and Technology Special Publication
NTP	Network Time Protocol
OT	Operational Technology
PII	Personally Identifiable Information
PLC	Programmable Logic Controller
RFC	Request for Comment
SD	Secure Digital
VHD	Virtual Hard Drive

3.5.17 Definitions

Term	Definition
Sensitive	Proprietary, customer, trades secret or other information with access restricted to those with legitimate business need. Unauthorized disclosure is against laws or regulations, and will likely harm the company, its business partners, or customers (e.g., trade secrets, source code, personnel data, PII).
Incident	An occurrence that actually or potentially jeopardizes the availability, integrity, or confidentiality of the manufacturing system or the information the system processes, stores, or transmits or that constitutes a violation or imminent threat of violation of security policies, security procedures, or acceptable use policies.
Internal Use	Data intended for internal company use, other affiliated organizations, or business partners. Unauthorized disclosure may be against laws or regulations and may cause harm the company or its business partners or its customers.
Personnel	All employees, contractors, vendors, and individuals authorized to perform work at the facility, physically or remotely.
Public	Data previously approved for release or is publicly available.

Term	Definition
Stakeholder	Individual or organization having a right, share, claim, or interest in a system or in its possession of characteristics that meet their needs and expectations. (e.g., Business Owners, System Owners, Integrators, Vendors, Human Resources Offices, Physical and Personnel Security Offices, Legal Departments, Operations Personnel).
Vulnerability	Weakness in an information system, system security procedures, internal controls, or implementation that could be exploited or triggered by a threat source.

3.6 System Recovery Plan Document Example

This section provides example content that a System Recovery Plan document may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

System Recovery Plan

for

Westman

Document Owner:	Director of Operations

Version

Version	Date	Description	Author
1.0	02-22-2018	Initial Draft	Director of Operations
2.0	04-21-2018	Major changes to the initial draft	Director of Operations

Approval

(By signing below, approvers agree to all terms and conditions outlined in this document.)

Approvers	Role	Signed	Approval Date
S. Forthright	CEO	<digital signature>	4-22-2018

3.6.1 Purpose

The System Recovery Plan is designed to ensure the continuation of vital manufacturing/business processes in the event a cybersecurity incident occurs. Its purpose is to provide a structured approach for responding to cybersecurity incidents by leveraging the infrastructure inventory and configuration information relevant to the organization's IT and OT environments to restore operational capabilities.

3.6.2 Objectives

This System Recovery Plan has been developed to accomplish the following objectives:

- limit the magnitude of any loss by minimizing the duration of a manufacturing interruption,
- assess damage, repair the damage, and restore manufacturing system operation,
- manage the recovery operation in an organized and effective manner, and
- prepare personnel to respond effectively in system recovery situations.

3.6.3 Plan Execution

This plan is executed during or after a cybersecurity incident, as directed by the Director of Operations.

3.6.4 Roles and Responsibilities

The Incident Response team will be repurposed as the System Recovery team while execution of the System Recovery Plan is ongoing. Team members will have the following roles and responsibilities:

Role	Responsibilities
Director of Operations	• Lead and oversee the entire system recovery process. • Contact any contractors or vendors for assistance, as needed. • Make sure all employees understand their roles and responsibilities. • Update this document as per the Maintenance Policy. • Update the CEO periodically on the progress of the system recovery process.
Chief Executive Officer (CEO)	• Assist the Director of Operations in their role as required. • Serve as point of escalation for any issues.
Control Engineers, IT Staff	• Recover, restore, troubleshoot, and resolve any recovery issues on manufacturing system hardware, software, or systems. • Escalate any issues related to recovery to the Director of Operations. • Comply with this plan.
OT Contractors	• Assist with the recovery of any manufacturing system hardware, software, or systems, as required. • Advise the Director of Operations of any recommended procedures, policies, and best practices to assist with the recovery process. • Comply with this plan.

3.6.5 Internal and External Communications

All communications guidance provided in the Incident Response Plan also applies to the System Recovery Plan. The following recovery-specific guidance must also be followed:

- The CEO will contact primary partners and customers to inform them about recovery activities. This should be performed once the impact of the incident is understood, and a corporate response has been prepared.
- The Director of Operations will contact all personnel responsible for system recovery, listed below, once this plan is executed.
- The General Counsel will be involved throughout the system recovery process due to the potential for legal action arising from the cybersecurity incident.
- The Director of Operations, IT Manager, and Control Engineers will periodically update the CEO and other stakeholders on the progress of recovery activities. The CEO will define the required stakeholders and update period based on the impact of the incident.
- Communications with external entities must be initiated by personnel explicitly authorized by this plan, or as authorized by the Director of Operations during execution of this plan.

3.6.6 Restoring Trust

- The CEO or Director of Operations, with the advice of any contracted consultants and forensic experts, will notify all partners, vendors, and customers of the steps taken to restore the manufacturing system and strengthen cybersecurity controls.
- The Director of Operations and IT Manager will discuss with employees the cause for the plan to be executed and what actions are being taken to avoid similar incidents from occurring in the future.
- After the cybersecurity incident has been mitigated and all facts surrounding the incident are known, the Director of Operations will provide a full report to be released publicly. The report will contain content relevant to the cybersecurity incident, along with the steps being taken to safeguard the manufacturing system, and describe the actions being taken to avoid similar incidents from occurring in the future.

3.6.7 Personnel Contact Information

The following table contains the contact information for critical Westman personnel who will likely be involved in the system recovery process.

Name	Title	Contact Type	Contact Information
S. Forthright	Chief Executive Officer (CEO)	Work	301-555-0141 ext. 102
		Mobile	240-555-0159
		Alternate	301-555-3554
		Email	s.forthright@nist-westman.com
W. Lumbergh	Director of Operations	Work	301-555-0141 ext. 103
		Mobile	240-555-0110
		Alternate	301-555-3110
		Email	w.lumbergh@nist-westman.com
E. Dufresne	Control Engineer	Work	301-555-0141 ext. 110
		Mobile	240-555-0543
		Alternate	301-555-3543
		Email	e.dufresne@nist-westman.com
M. West	General Counsel	Work	301-555-0141 ext. 107
		Mobile	240-555-2173
		Alternate	301-555-3173
		Email	m.west@nist-westman.com
E. Kenmore	IT Manager	Work	301-555-0141 ext. 108
		Mobile	240-555-0824
		Alternate	301-555-3824
		Email	e.kenmore@nist-westman.com
J. Smith	HR Manager	Work	301-555-0141 ext. 109
		Mobile	240-555-0543
		Alternate	301-555-3543
		Email	j.smith@nist-westman.com

3.6.8 External Contact Information

The following table contains the contact information for external entities and organizations that may be contacted while execution of the System Recovery Plan is ongoing to support or provide relevant information to support the recovery process. External entities and organizations listed below must only be contacted by authorized personnel, as per the guidance described in this System Recovery Plan.

Name	Title	Contact Type	Contact Information
OT Contractor Cyberdyne Systems Account # 88525462A	General Support	Work	1-800-555-6543 Option 1, 3, 5
		Mobile	N/A
		Alternate	N/A
		Email	support@cyberdynesystems.com
Power Company Account # 5486548	General Support	Work	1-800-555-4343 Option 1,4,7,9
		Mobile	N/A
		Alternate	N/A
		Email	N/A
Telecom Carrier Account # 3340444	General Support	Work	1-800-555-8769
		Mobile	N/A
		Alternate	N/A
		Email	N/A
Insurance Provider Account # 8858444	Agent (R. Parr)	Work	1-800-555-7643
		Mobile	240-555-5698
		Alternate	240-555-5433
		Email	r.parr@insuricare.com

3.6.9 Plan Maintenance

The System Recovery Plan must be reviewed and updated after:

- the plan is executed in response to a cybersecurity incident,
- the plan is executed during an incident response or recovery exercise,
- any organizational changes, or
- any modifications or maintenance to the manufacturing system or its components that may impact this plan.

The Director of Operations is responsible for updating the document in consultation with Controls Engineers and other personnel, as required.

3.6.10 Plan Testing

This plan must be tested during planned downtime each calendar year. During this time, System Recovery team members must be convened to perform the following activities:

- system recovery tabletop exercises,
- review of the documented procedures,
- validation of plan effectiveness,
- identification of any gaps or weaknesses in the plan execution, and
- update the plan with any outdated or missing information.

3.6.11 Hardware to be Recovered

The following tables document important information to support the recovery of manufacturing system devices. Each device is listed in its own table with relevant information (e.g., hostname, file systems, physical location, backup strategies). The recovery strategies for each device below is described in Section 3.6.12. For more detailed system information regarding each host, reference the Hardware Inventory.

3.6.11.1 Plant Servers

Engineering Workstation	
Hostname	FGS-47631EHH
Model	HP Z230
IP Address	172.16.3.10
Network	Engineering LAN
Location	Cabinet 101
Type	Physical
Operating System	Windows 7
File System(s)	C: (465GB)
Backup Strategies	Veeam directory backups are performed on select directories containing configuration and logic data for the manufacturing system: • weekly during periods of low volume production (e.g., overnight).
	Veeam full system image backups are performed: • quarterly during periods of low volume production (e.g., overnight), and • after engineering change.
Recovery Priority	Medium
Recovery Strategies	Veeam Directory Recovery (Section 3.6.12.1)
	Veeam Full Image Recovery (Section 3.6.12.2)

OPC Server	
Hostname	FGS-61338OSH
Model	Supermicro Z97X
IP Address	172.16.2.5
Network	Supervisory LAN
Location	Cabinet 101
Type	Physical
Operating System	Windows 7
File System(s)	C: (233 GB)
	O:\OPC_Share (\\172.16.2.5)
Backup Strategies	Veeam full system image backups are performed: • quarterly during periods of low volume production (e.g., overnight), and • after engineering change.
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Process Controller Server	
Hostname	FGS-61338CH
Model	Supermicro Z97X
IP Address	172.16.1.5
Network	Operations LAN
Location	Cabinet 101
Type	Physical
Operating System	Windows 7
File System(s)	C: (233 GB)
Backup Strategies	Veeam full system image backups are performed: • quarterly during periods of low volume production (e.g., overnight), and • after engineering change.
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

HMI Host Server	
Hostname	FGS-61338HH
Model	Supermicro Z97X
IP Address	172.16.1.4
Network	Operations LAN
Location	Cabinet 101
Type	Physical
Operating System	Windows 7
File System(s)	C: (233 GB)
	O:\OPC_Share (\\172.16.2.5)
Backup Strategies	Veeam full system image backups are performed: • quarterly during periods of low volume production (e.g., overnight), and • after engineering change.
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Local Historian Host	
Hostname	FGS-61338LHH
Model	Supermicro Z97X
IP Address	172.16.2.5
Network	Supervisory LAN
Location	Cabinet 101
Type	Physical
Operating System	Windows 7
Hosted VMs	Local Historian Database Virtual Machine (WIN-FPVTDCDEUCR)
File System(s)	C: (233 GB)
	O:\OPC_Share
Backup Strategies	Veeam full system image backups are performed: • quarterly during periods of low volume production (e.g., overnight), and • after engineering change.
	OSIsoft PI historian data of the manufacturing process is duplicated in real-time to the DMZ Historian (PI-DMZ).
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Local Historian Database Virtual Machine	
Hostname	WIN-FPVTDCDEUCR
Model	N/A
IP Address	172.16.2.14
Network	Supervisory LAN
Location	Local Historian Server (FGS-61338LHH)
Type	Virtual Machine
Operating System	Windows Server 2008
File System(s)	C: (50 GB, VHD)
	W:\Eng_Workstation (\\172.16.3.10)
Backup Strategies	Backup of the VHD is handled by the Veeam full system image of the host server, Local Historian Host (FGS-61338LHH).
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2) of host file system (FGS-61338LHH).

Controller PLC	
Model	Allen-Bradley Logix 5571
IP Address	172.16.2.102
Network	Supervisory LAN
Location	Cabinet 101
Type	Physical
Backup Strategies	Backup of the PLC project files is handled by the Veeam full system image of the Engineering Workstation (FGS-47631EHH), as the files are stored locally on that host.
	Veeam full image backups of Engineering Workstation (FGS-47631EHH) must be manually performed after any engineering changes to the PLC project or its configuration.
	Backup of the SD card contents is performed annually during the plant shutdown.
Recovery Priority	High
Recovery Strategies	PLC Logic Recovery (Section 3.6.12.4)
	PLC SD Card Recovery (Section 3.6.12.5)
	PLC Firmware Recovery (Section 3.6.12.6)

3.6.11.2 Network Devices

Manufacturing System Router / Firewall	
Hostname	CiscoASA
Model	Cisco ASA 5512
IP Address(es)	Corporate Network: REDACTED Cybersecurity LAN: 10.100.0.1 DMZ LAN: 10.100.1.1 Management LAN: 10.100.2.4
Location	Cabinet 102
Type	Physical
Operating System	Firmware: FTD 6.2.3.7 Build 51
Backup Strategies	Manual. Performed via the CLI or web UI.
Recovery Priority	High
Recovery Strategies	Cisco ASA Recovery (Section 3.6.12.7)

Boundary Router	
Model	Allen-Bradley 8300
IP Address	10.100.2.8
Location	Cabinet 101
Type	Physical
Operating System	Firmware: V15.2(4a) EA5 Crypto
Backup Strategies	Manual. Performed through CLI or web UI
Recovery Priority	High
Recovery Strategies	Allen-Bradley 8300 Recovery (3.6.12.8)

Supervisory LAN Switch	
Model	Allen-Bradley 5700
IP Address	172.16.2.2
Location	Cabinet 101
Type	Physical
Operating System	Firmware: v15.2(5)EA.fc4
Backup Strategies	Manual. Performed through CLI or web UI
Recovery Priority	High
Recovery Strategies	Allen-Bradley 5700 Recovery (3.6.12.9)

Control LAN Switch	
Model	Allen-Bradley 5700
IP Address	172.16.1.3
Location	Cabinet 101
Type	Physical
Operating System	Firmware: v15.2(5)EA.fc4
Backup Strategies	Manual. Performed through CLI or web UI
Recovery Priority	High
Recovery Strategies	Allen-Bradley 5700 Recovery (3.6.12.9)

3.6.11.3 Cybersecurity LAN Servers

Hyper-V Host Server	
Hostname	LANVH
Model	Dell PowerEdge R620
IP Address	10.100.2.10
Network	Management LAN (Hosted VMs are on Cybersecurity LAN)
Location	Cabinet 102
Type	Physical
Operating System	Windows Server 2012 R2 Datacenter x64 Edition
Hosted VMs	• LAN-AD • LAN-AD02 • SymantecMgrVM • Security Onion • Graylog • GTBInspector • GTBCC • The-Hive • NessusVM • WSUS
File System(s)	C: (1 TB)
	D: (3.5 TB)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Active Directory Server	
Hostname	LAN-AD
Model	N/A
IP Address	10.100.0.13
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Windows Server 2012 R2
File System(s)	45 GB (VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Backup Active Directory Server	
Hostname	LAN-AD02
Model	N/A
IP Address	10.100.0.17
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Windows Server 2012 R2
File System(s)	250 GB (VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	High
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

DMZ Historian	
Hostname	PI-DMZ
Model	N/A
IP Address	10.100.1.4
Network	Manufacturing DMZ
Location	Cabinet 102
Type	Virtual
Operating System	Windows 2008 R2 Standard Edition
File System(s)	250 GB (VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
	The native OSIsoft PI application backup feature archives production data from the manufacturing process. These backups are stored on the local host; restore the host to obtain the most recent backup version. NOTE: Any recovered historical data will be limited to data present at the time of the backup.
Recovery Priority	Medium
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)
	OSIsoft PI production data recovery.

VMware Host	
Hostname	ESXi-Host
Model	Dell R710
IP Address	10.100.2.9
Network	Management LAN
Location	Cabinet 102
Type	Physical
Operating System	vmWare vSphere ESXi 6.0.0
Hosted VMs	• PI-DMZ • Veeam
File System(s)	4.5 TB (DataStore1)
Backup Strategies	Manual. Performed through CLI or web UI
Recovery Priority	High
Recovery Strategies	VMWare ESXi Recovery (3.6.12.11)

Veeam Backup Server	
Hostname	Veeam
Model	N/A
IP Address	10.100.0.10
Network	Cybersecurity LAN
Location	VMware Host (ESXi-Host)
Type	Virtual
Operating System	Windows Server 2012 R2
File System(s)	C: (50 GB, VHD)
	E: (500 GB, VHD)
	F: (4 TB, VHD)
	Network Share (Host, F:\Backup\Network Devices)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	High
Recovery Strategies	Veeam Instant Virtual Machine Recovery (3.6.12.3)

Symantec Antivirus Server	
Hostname	SymantecMgrVM
Model	N/A
IP Address	10.100.0.5
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Windows Server 2012 R2
File System(s)	70 GB (VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Medium
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Security Onion Server	
Hostname	Security Onion
Model	N/A
IP Address	10.100.0.26
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Ubuntu 16.04
File System(s)	Root File System (500 GB, VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Low
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Graylog Server	
Hostname	Graylog
Model	N/A
IP Address	10.100.0.14
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Ubuntu 14.04
File System(s)	Root File System (50 GB)
	Data File System (500 GB)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Low
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

GTB Inspector Server	
Hostname	GTBInspector
Model	N/A
IP Address	10.100.0.175
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	CentOS 7.4.1708
File System(s)	162 GB (Vendor configured)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Low
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

GTB Console Server	
Hostname	GTBCC
Model	N/A
IP Address	10.100.0.176
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	CentOS 7.4.1708
File System(s)	107 GB (vendor configured)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Low
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

The Hive Project Incident Response Server	
Hostname	The-Hive
Model	N/A
IP Address	10.100.0.51
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Ubuntu 16.04
File System(s)	Root file system (50 GB, VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Low
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Nessus Vulnerability Scanner Server	
Hostname	NessusVM
Model	N/A
IP Address	10.100.0.25
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Windows Server 2012 R2
File System(s)	C: (65 GB, VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Medium
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

Windows WSUS Server	
Hostname	WSUS
Model	N/A
IP Address	10.100.0.12
Network	Cybersecurity LAN
Location	Hyper-V Host Server (LANVH)
Type	Virtual
Operating System	Windows Server 2012 R2
File System(s)	C: (400 GB, VHD)
Backup Strategies	Veeam full system image backups are performed: • daily overnight, and • after any configuration change.
Recovery Priority	Low
Recovery Strategies	Veeam Full Image Recovery (Section 3.6.12.2)

NTP Server	
Hostname	NTPSrv
Model	Meinberg LANTIME M900
IP Address	10.100.0.15
Network	Cybersecurity LAN
Location	Cabinet 102
Type	Physical
Operating System	Firmware: 6.20.023
Backup Strategies	Configuration backups are performed manually via the device web interface: • after any configuration change. Configuration backup files are transferred manually (i.e., via flash drive or network share) and are stored in the Veeam server.
Recovery Priority	Medium
Recovery Strategies	Vendor-specified recovery procedures (Section 3.6.12.10)

3.6.12 Recovery Procedures

The following table defines generalized recovery procedures manufacturing system devices.

3.6.12.1 Veeam Directory Level Recovery

Directory level (file-level) backups enable restoration and recovery of individual files and folders. Data required for this type of restoration are stored in the Veeam Server. Reference Veeam guidance[41] to complete the restoration process.

Warning: The manufacturing system must be in a non-operational state when the recovery is performed if the host to be recovered is in the Operations LAN or Supervisory LAN.

3.6.12.2 Veeam Full Image Recovery

Full image (volume-level) backups enable restoration and recovery of a host, or specific volumes of the host file system. Data required for this type of restoration are stored in the Veeam Server. Reference Veeam guidance[42] to complete the restoration process.

Warning: The manufacturing system must be in a non-operational state when the recovery is performed if the host to be recovered is in the Operations LAN or Supervisory LAN.

3.6.12.3 Veeam Instant Virtual Machine Recovery

Virtual Machine backups enable full system images to be created, similar to Veeam Full Image backups for physical hosts. These types of backups can be used for recovery of files, file systems, and complete restoration. Reference Veeam guidance for Hyper-V[43], VMWare[44], and Veeam[45] to complete the restoration process.

3.6.12.4 PLC Logic Recovery

PLC logic recovery can be performed to restore the PLC logic back to a known state in case of compromise or corruption. This operation must be performed from the Engineering Workstation. Reference Allen-Bradley PLC guidance[46] to complete the restoration process.

Warning: The manufacturing system must be in a non-operational state when this recovery is performed.

[41] https://helpcenter.veeam.com/docs/backup/vsphere/restore_vead.html?ver=95u4
[42] https://www.veeam.com/veeam_backup_9_5_u4_enterprise_manager_user_guide_pg.pdf
[43] https://helpcenter.veeam.com/docs/backup/hyperv/data_recovery.html?ver=95u4
[44] https://helpcenter.veeam.com/docs/backup/vsphere/data_recovery.html?ver=95u4
[45] https://helpcenter.veeam.com/docs/backup/vsphere/vbr_config_restore.html?ver=95u4
[46] https://literature.rockwellautomation.com/idc/groups/literature/documents/pm/1756-pm014_-en-p.pdf

3.6.12.5 PLC SD Card Recovery

PLC SD card recovery can be performed to rapidly restore the PLC logic back to an operational state in case of compromise or corruption. The following is a high-level overview of the process. Additional details are available in manufacturer documentation.[47]

1. Power off the PLC and remove the SD card from the front of the device.
2. Insert the SD card into the Engineering Workstation.
3. Delete all existing contents from the SD card, or simply reformat the card.
4. Copy and paste the files from the most recent backup onto the SD card.
5. Safely remove the SD card from the Engineering Workstation.
6. Insert the SD card into the PLC and power on the device.

Notice: This recovery can only restore the logic; it will not restore any configuration of the PLC or other modules within the chassis.

Warning: Do not use this recovery method if the PLC or any of the other modules have been replaced as part of this recovery.

Warning: The manufacturing system must be in a non-operational state when this recovery is performed.

3.6.12.6 PLC Firmware Recovery

PLC firmware recovery can be performed to restore the PLC operating system. This operation must be performed from the Engineering Workstation.

1. Download the most recent firmware image from the Beckhoff website.[48]
2. Power off the PLC and remove the SD card from the front of the device.
3. Insert the SD card into the Engineering Workstation.
4. Delete all existing contents from the SD card, or simply reformat the card.
5. Copy and paste the new firmware files from the most recent backup onto the SD card.
6. Safely remove the SD card from the Engineering Workstation.
7. Insert the SD card into the PLC and power on the device.
8. Connect to the PLC from the Engineering Workstation TwinCAT software, open the PLC project, activate the configuration, and deploy the PLC project.
9. Disconnect from the PLC.

Warning: The manufacturing system must be in a non-operational state when this recovery is performed.

[47] https://literature.rockwellautomation.com/idc/groups/literature/documents/pm/1756-pm017_-en-p.pdf
[48] https://infosys.beckhoff.com

3.6.12.7 Cisco ASA 5512 Recovery

Recovery procedures can be performed to restore the Cisco ASA 5512 back to a known state in case of compromise or corruption. This operation must be performed from a device connected to the Cybersecurity LAN. Reference Cisco guidance[49] to complete the restoration process.

3.6.12.8 Allen-Bradley 8300 Recovery

In most cases, restoring the configuration may be enough, however, in certain situations, performing the vendor-specified factory reset procedure before restoring may be required. To perform the factor reset, perform the following steps:

1. Begin by removing the power from the switch.
2. Next, press the Express Setup button with a thin wire or paperclip while applying power.
3. Release the button when you see 3 LED's on the front of the unit (EIP Mod, EIP Net and Setup) turn red. The switch will continue to boot normally. (Approximately 3 min)
4. Restore configuration from archived configuration backups. Refer to the user manual for detailed instructions[50].

3.6.12.9 Allen-Bradley 5700 Recovery

In most cases, restoring the configuration may be enough, however, in certain situations, performing the vendor-specified factory reset procedure before restoring may be required.

To perform the factor reset, perform the following steps:

From the Device Manager:

1. From the menu, go to Admin > Restart/Reset.
2. On the Restart / Reset tab, click Reset the switch to factory defaults, and then restart the switch.
3. Restore configuration from archived configuration backups. Refer to the user manual for detailed instructions[51].

3.6.12.10 NTP Server Recovery

NTP Server recovery can be performed through the device web interface[52]. If the device is not operational, attempt to perform the vendor-specified Factory Reset procedure via the display/keypad on the front of the device. Once the device is operational, restore configuration from archived configuration backups via the web interface.

[49] https://www.cisco.com/c/en/us/td/docs/security/asa/roadmap/asaroadmap.html
[50] https://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf
[51] https://literature.rockwellautomation.com/idc/groups/literature/documents/um/1783-um007_-en-p.pdf
[52] https://www.meinbergglobal.com/download/docs/manuals/english/m900_gps.pdf

3.6.12.11 VMWare ESXi Recovery

Reload the same version of ESXi from trusted media and restore the configuration from the backup archives (see VMWare KB[53] for additional details). One method utilizing the ESXi Console is detailed below.

From ESXi Console:

1. Put the host into maintenance mode by running the command:
   vim-cmd hostsvc/maintenance_mode_enter

2. Copy the backup configuration file to the host's /tmp directory using SCP and name it configBundle.tgz.

3. Run the following command to restore the configuration:
   vim-cmd hostsvc/firmware/restore_config /tmp/configBundle.tgz

   Note: Executing this command will initiate an automatic reboot of the host after command completion.

4. Restore the individual virtual machines from Veeam backup archives following Veeam Instant Virtual Machine Recovery procedures (Section 3.6.12.3).

[53] https://kb.vmware.com/s/article/2042141

3.7 Service Level Agreement

This section provides example content that a Vendor Service Level Agreement may contain, including example policy and procedure statements that were developed for the fictional company Westman. Certain commercial entities, equipment, or materials may be identified in this document in order to describe a concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, equipment, or materials are necessarily the best available for the purpose. Each organization's information security experts should identify the content, and policy and procedure statements that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

Service Level Agreement (SLA)

for *Vendor*

by

Westman

Effective Date: 02-22-2019

Document Owner:	CEO

Version

Version	Date	Description	Author
1.0	02-22-2019	Service Level Agreement	CEO

Approval

(By signing below, approvers agree to all terms and conditions outlined in this Agreement.)

Approvers	Role	Signed	Approval Date
Westman	Customer	<digital signature>	2-22-2019
Vendor	Service Provider	<digital signature>	2-22-2019

3.7.1 Overview

This Agreement represents a Service Level Agreement ("SLA" or "Agreement") between Westman and Vendor (Service Provider) for the provisioning of IT/OT services required to support and sustain the product or service.

This Agreement remains valid until superseded by a revised agreement mutually endorsed by the stakeholders.

This Agreement outlines the parameters of all IT/OT services covered as they are mutually understood by the primary stakeholders. This Agreement does not supersede current processes and procedures unless explicitly stated herein.

3.7.2 Goals and Objectives

The purpose of this Agreement is to ensure that the proper elements and commitments are in place to provide consistent IT/OT service support and delivery to Westman by the Service Provider(s). The goal of this Agreement is to obtain mutual understanding for IT/OT services provision between the Service Provider and Westman.

The objectives of this Agreement are to:

- Provide clear reference to service ownership, accountability, roles and/or responsibilities.
- Present a clear, concise and measurable description of service provision to the customer.
- Match perceptions of expected service provision with actual service support and delivery.

3.7.3 Stakeholders

The following Service Provider and Westman will be used as the basis of the Agreement and represent the **primary stakeholders** associated with this SLA:

IT Service Provider: Service Provider
IT/OT Customer: Westman

3.7.4 Periodic Review

This Agreement is valid from the effective date outlined herein and is valid until further notice. This Agreement should be reviewed at a minimum once per fiscal year; however, in lieu of a review during any period specified, the current Agreement will remain in effect.

The **Business Relationship Manager** ("Document Owner") is responsible for facilitating regular reviews of this document. Contents of this document may be amended as required, provided mutual agreement is obtained from the primary stakeholders and communicated to all affected parties. The Document Owner will incorporate all subsequent revisions and obtain mutual agreements / approvals as required.

Business Relationship Manager: Westman (CEO)
Review Period: Yearly (12 months)
Previous Review Date: 02-22-2019
Next Review Date: 02-22-2020

3.7.5 Service Scope

The following Services are covered by this Agreement:

- Apply system updates to manufacturing environment per vendor's recommendation
- Apply system updates to IT equipment when patches are released per vendor.
- Backup configure information for all IT/OT equipment within Westman
- Ensure cybersecurity tools are operating correctly within the environment
- Provide liaison service between OT vendor and Westman
- Product recommendation for new equipment being purchased and installed with Westman's manufacturing environment
- Manned telephone support
- Monitored email support
- Remote assistance using Remote Desktop and a Virtual Private Network where available
- Planned or Emergency Onsite assistance (extra costs apply)
- Monthly system health check

3.7.6 Westman's Requirements

Westman's responsibilities and requirements in support of this Agreement include:

- Payment for all support costs at the agreed interval.
- Reasonable availability of Westman representative(s) when resolving a service-related incident or request.

3.7.7 Service Provider Requirements

Service Provider responsibilities and/or requirements in support of this Agreement include:

- Meeting response times associated with service-related incidents.
- Appropriate notification to Westman for all scheduled maintenance.

3.7.8 Service Assumptions

Assumptions related to in-scope services and/or components include:

- Changes to services will be communicated and documented to all stakeholders.

3.7.9 Service Management

Effective support of in-scope services is a result of maintaining consistent service levels. The following sections provide relevant details on service availability, monitoring of in-scope services and related components.

3.7.10 Service Availability

Coverage parameters specific to the service(s) covered in this Agreement are as follows:

- Telephone support: 8:00 A.M. to 5:00 P.M. Monday – Friday
    - Calls received out of office hours will be forwarded to a mobile phone and best efforts will be made to answer / action the call, however there will be a backup answer phone service
- Email support: Monitored 8:00 A.M. to 5:00 P.M. Monday – Friday
    - Emails received outside of office hours will be collected, however no action can be guaranteed until the next working day
- Onsite assistance guaranteed within 72 hours during the business week

3.7.11 Service Requests

In support of services outlined in this Agreement, the Service Provider will respond to service-related incidents and/or requests submitted by Westman within the following time frames:

- 0 to 8 hours (during business hours) for issues classified as **High** priority.
- Within 48 hours for issues classified as **Medium** priority.
- Within 5 working days for issues classified as **Low** priority.

Remote assistance will be provided at the discretion of Westman in-line with the above timescales and dependent on the priority of the support request. The service provider may not utilize remote access as an alternative for providing onsite support as described in section 3.7.10 of this agreement.

3.7.12 Personnel Changes

The Service Provider will notify Westman within 24 hours when an individual supporting Westman leaves the Service Provider or is transferred. Westman will disable remote access, if granted, for the individual within 24 hours of notification. The Service Provider will revoke the individual's access to Westman information and information systems within 24 hours. Additionally, any system account passwords the individual had will need to be changed to ensure user access into the network has been completely removed.

4. Technical Solution Implementations

4.1 Introduction

This section includes proof-of-concept technical solution implementations developed for the fictional company Westman. An overview of these technical solutions is discussed in Section 6 of Volume 1 and potential technical solutions are discussed in Section 7 of Volume 1. Each organization's information security experts should identify the technical solutions that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

There are five main areas of performance indicators being collected in the Process Control System (PCS):

1. **Manufacturing process performance:** measures the performance of the manufacturing process, i.e. the chemical continuous process.
2. **Network performance:** measures the performance of the underlying TCP/IP network.
3. **Computing resources performance:** measures the performance of the computers, hardware, and software processes.
4. **Industrial protocol performance:** measures the performance of the industrial communication protocol, i.e. the DeviceNet in the PCS.
5. **OPC Data Exchange performance:** measures the performance of the data exchange mechanism of the system.

Measurements in different areas provide insight of the entire system performance from different perspectives. The manufacturing process performance provides indicators on how well the high-level manufacturing process and overall system perform. However, this may not be able to provide enough detail on the performance of the sub-systems, therefore measurements are also performed at sub-system levels. For example, a typical chemical continuous manufacturing is a relatively slow process in comparison with available network bandwidth. Therefore, a moderate TCP/IP network delay may not reflect in the measurement of the high-level manufacturing process performance. However, such TCP/IP delay may have significant impact on the sub-systems. The effects will not be reflected in the high-level measurement until significant delays are accumulated in sub-systems. Measurements in multiple levels provide details and in-depth understanding to key performance areas of the entire system. It helps to understand how the aggregate effects will impact the performance. Aggregate effects will be important to the high-level manufacturing performance.

Each technical solution implementation is organized as an experiment. For the measurement purpose, each experiment has a fixed runtime of 4 hours (14 400 seconds). Performance metrics and network packet capture are collected during the entire experiment run.

After the experiment is completed, all the collected metrics and network packet capture will go through the post processing stage to filter, sort and rearrange data in proper order. The last step is to compute the key performance indicators from the sorted dataset using a set of Python scripts developed by NIST.

Additional technical detail of the Process Control System and the measurement process is described in NISTIR 8188.[54]

4.1.1 Implementation Note – Due Diligence Implementing Technical Solutions

It is important to note that the procedures used during this implementation (i.e., install a tool, then measure the impact) should not be used in a production system. Care must be taken before using any technical solutions, especially those that actively scan the manufacturing system network and its devices; manufacturers should first assess how these tools work and what impact they might have on the connected control equipment [3]. Technology evaluations may include testing in similar, non-production control system environments to ensure that the tools do not adversely impact the production systems. Impact could be due to the nature of the information or the volume of network traffic. While this impact may be acceptable in IT systems, it may not be acceptable in a manufacturing system. In general, any operation that actively scans the manufacturing network should be scheduled to occur only during planned downtimes. [3]

> Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose. Each organization's information security experts should identify the technical solutions that will best integrate with their existing cybersecurity program and manufacturing system infrastructure.

[54] NISTIR 8188: Key Performance Indicators for Process Control System Cybersecurity Performance Analysis.

4.1.2 Implementation Note - Availability of Measurement Data

All raw and processed measurement data captured from each experiment is freely available online at: https://doi.org/10.18434/M32071.

Links to each of the data files are provided below, and directly referenced at the end of each implementation.

- Open-AudIT KPI data
- Open-AudIT measurement data
- Wireshark KPI data
- Wireshark measurement data
- Veeam full backup KPI data
- Veeam full backup measurement data
- Veeam incremental backup KPI data
- Veeam incremental backup measurement data
- Cisco VPN KPI data
- Cisco VPN measurement data
- Active Directory KPI data
- Active Directory measurement data
- Symantec AV KPI data
- Symantec AV measurement data
- Nessus KPI data
- Nessus measurement data
- File Encryption KPI data
- File Encryption measurement data
- Firewall KPI data
- Firewall measurement data

4.2 Open-AudIT

4.2.1 Technical Solution Overview

Open-AudIT is an asset inventory tool providing scanning of hardware and software within the manufacturing environment. Open-AudIT scans are highly customizable to each environment, depending on the level required.

Open-AudIT cost depends on the level of functionality desired for your environment. Editions offered by Open-AudIT vary from entry level community edition which is free, all the way up to enterprise edition. Enterprise was chosen since it contains the ability to setup scheduled scanning, dashboards, and baselining of equipment.

Open-AudIT is a downloadable Open Virtual Appliance (OVA) which is easy to install. OVA install allows installation in a hypervisor environment allowing for installation within an existing virtual environment without requiring purchasing additional hardware. Configuration for initial discovery scans is straightforward.

4.2.2 Technical Capabilities Provided by Solution

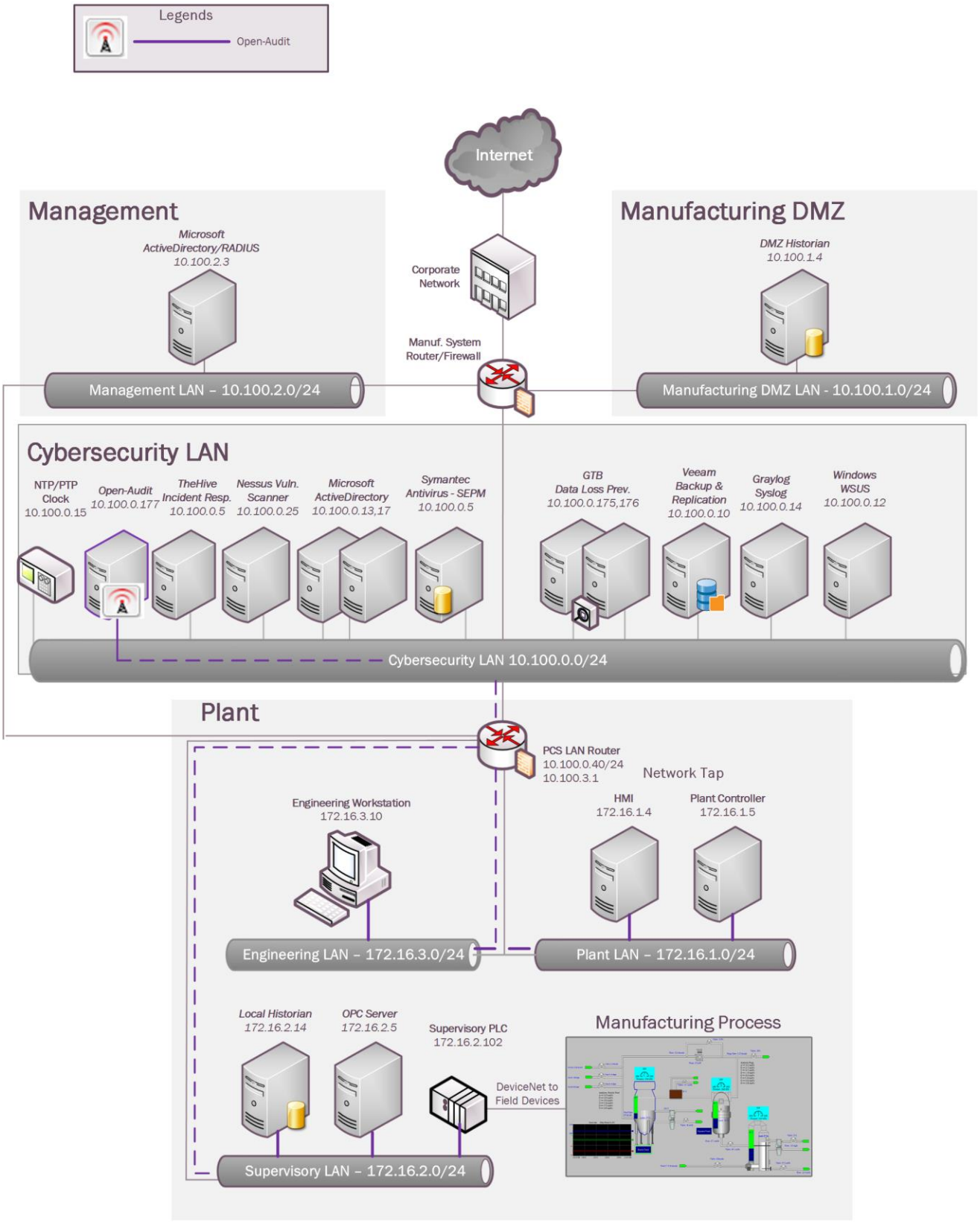
Open-AudIT provides components of the following Technical Capabilities:

- Hardware Inventory
- Software Inventory
- Systems Development Lifecycle Management
- Configuration Management
- Baseline Establishment (Enterprise Edition)
- Change Control

4.2.3 Subcategories Addressed by Implementing Solution

ID.AM-1, ID.AM-2, ID.AM-3, ID.AM-4, PR.DS-3, PR.IP-1, PR.IP-2, PR.IP-3, PR.IP-4, PR.IP-6, PR.MA-1, DE.AE-1, DE.CM-7

4.2.4 Architecture Map of Where Solution was Implemented



4.2.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware details
Open-AudIT	3.0.0	Hyper-V Virtual Machine (Generation 1): • Processors: 2 virtual cores • Memory: 2 GB • Disk space: Allocated by the Virtual Appliance files provided by the vendor. • Network: 1 interface • Operating System: CentOS 7

4.2.5.1 Open-Audit Environment setup

1. A virtual machine running CentOS Linux 7 as provided by the Vendor with hardware specifications as described in the table above.
2. The guest OS IP information was set as follows:

```
IP address: 10.100.0.177
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

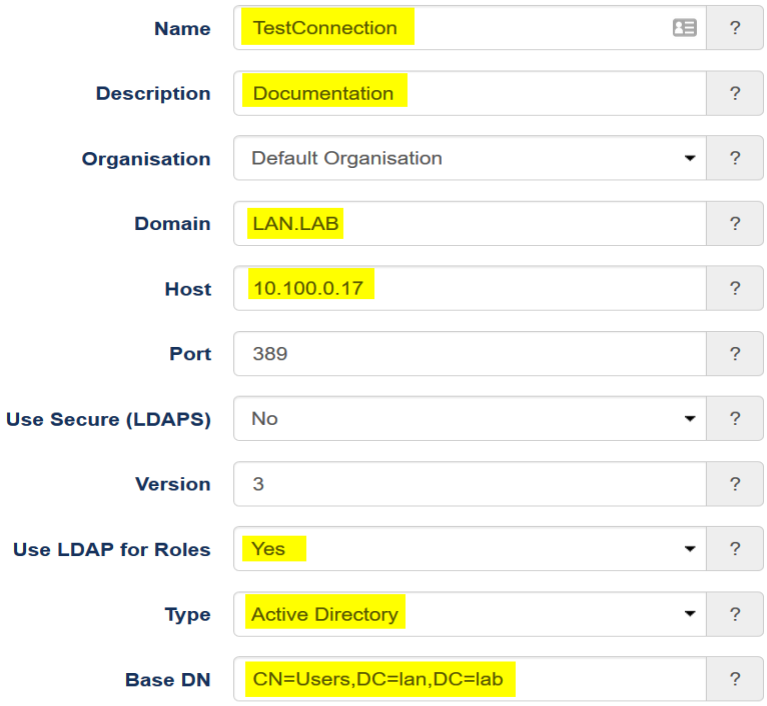
4.2.5.2 Setup Instructions

1. Download the Opmantek Virtual Appliance[55]
2. If deploying on a Hyper-V host server[56], convert the downloaded **.ova** file to **.vhdx** format.
3. Login using the default credentials, set a hostname and assign the VM a static IP address. Edit */etc./sysconfig/network-scripts/ifcfg-eth0* to set the networking information.
4. Restart networking services using the command `service network restart`.

[55] https://opmantek.com/
[56] https://blogs.msdn.microsoft.com/timomta/2015/06/11/how-to-convert-a-vmware-vmdk-_to-hyper-v-vhd/

4.2.5.3 Additional Setup via Web browser

1. Navigate to the Open-Audit Web UI (Example http://<ip-address-of-server>)
2. Select **Yes,** if prompted to proceed to untrusted site. This error is produced since SSL has not been configured and Open-AudIT redirects HTTP sessions over to HTTPS.
3. Click on **Open-AudIT Enterprise.**
4. Login using the default **username / password** mentioned on the webpage.
5. Click on **Admin > LDAP Server > Create LDAP Servers for** Active Directory integration.
   Screenshot of our Active directory connection provided for reference.



6. Click **Submit** once all information has been entered.

4.2.5.4 Active Directory Groups for LDAP Integration

- Create the following **Security** Groups of **Global** Type in your Active Directory to integrate with Open-AudIT.

```
open-audit_roles_admin
open-audit_roles_org_admin
open-audit_roles_reporter
open-audit_roles_user
open-audit_orgs_default_organisation
```

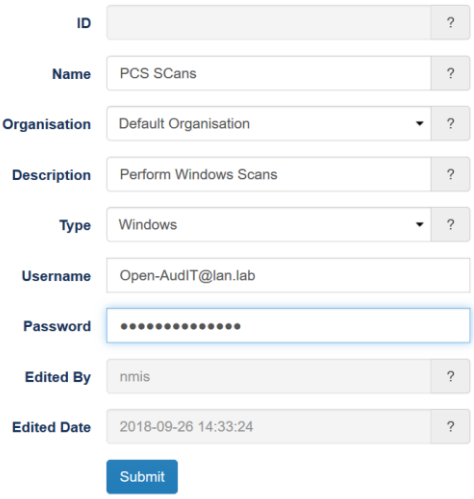
- Add the appropriate users to these groups. Test logging in with your Active Directory credentials.

4.2.5.5 Configuring Discover Credentials

1. Click on **Discover > Discoveries > Create Credentials.**
2. Enter the requested information:

Name – Name of the Credentials being used. Example (**SSH**)
Organization – Default Organization is selected. Pickup another if your configuring more the one organization.
Description – Description of item being added.
Type – Select which type of credentials will be used**. (SNMP (v1 / v2), SNMP v3, SSH, SSH Key, or Windows)**
Credentials – enter the appropriate credentials for the select type from above.

The image below shows Discover credentials created for scanning plant network.



3. Click **Submit**.

4.2.5.6 Organization Groups

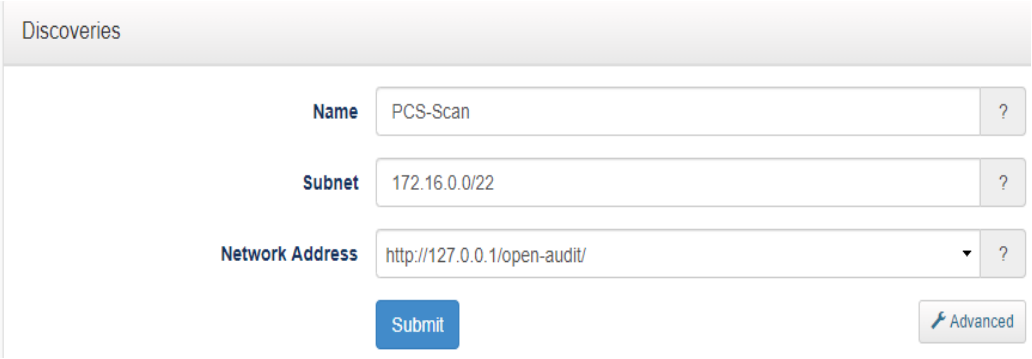
1. Click on **Manage** > **Orgs** > **Create Orgs**
2. Enter **Name** and **Description**.
3. Click **Submit.**

The image below shows an Organization Group created as per our environment

4.2.5.7 Discovery Scans

1. Click on **Discover** > **Discoveries** > **Create Discoveries**
2. Enter a name under **Name**.
3. Enter a network subnet to be scanned under **Subnet**.
4. Select the Open-Audit server under **Network Address**.
5. Click **Advanced** to setup additional options if desired. These options are **Org, Type, Devices Assigned to Org,** and **Devices Assigned to Location**.
6. Click **Submit.**

The image below shows Discovery scan created for scanning the plant network



4.2.5.8 Additional Information

1. Change all default passwords before deploying in production.
2. Use Secure LDAP (LDAPS). If unable to use LDAPS make sure account being used for syncing groups has least privilege rights. (Not an Administrator and not a Domain Administrator)
3. Use SNMPv3 whenever using SNMP for scanning devices.
4. Software is Open Source. Professional Edition allows up to 20 machines after that there is a cost which is relatively inexpensive. Upgrade to Enterprise Edition to perform system baselines scans.
5. For more information and hardware requirements, visit the Community forums[57]

[57] https://community.opmantek.com

4.2.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Open-AudIT tool while the manufacturing system was operational:

Experiment PL003.1- Open-AudIT asset inventory tool network scan and authenticated scan

A small performance impact to the network behavior was observed in the PCS system during the Open-AudIT scan. The network traffic was slightly increased in part of the PCS system during the scan. For example, the path delay from PLC to OPC was slightly higher especially in the latter part of the experience when Open-AudIT was performing the authenticated scan. However, the round trip time from the Controller to the OPC was mostly the same throughout the scan. It appears that some part of the system has a more noticeable impact than the other parts.

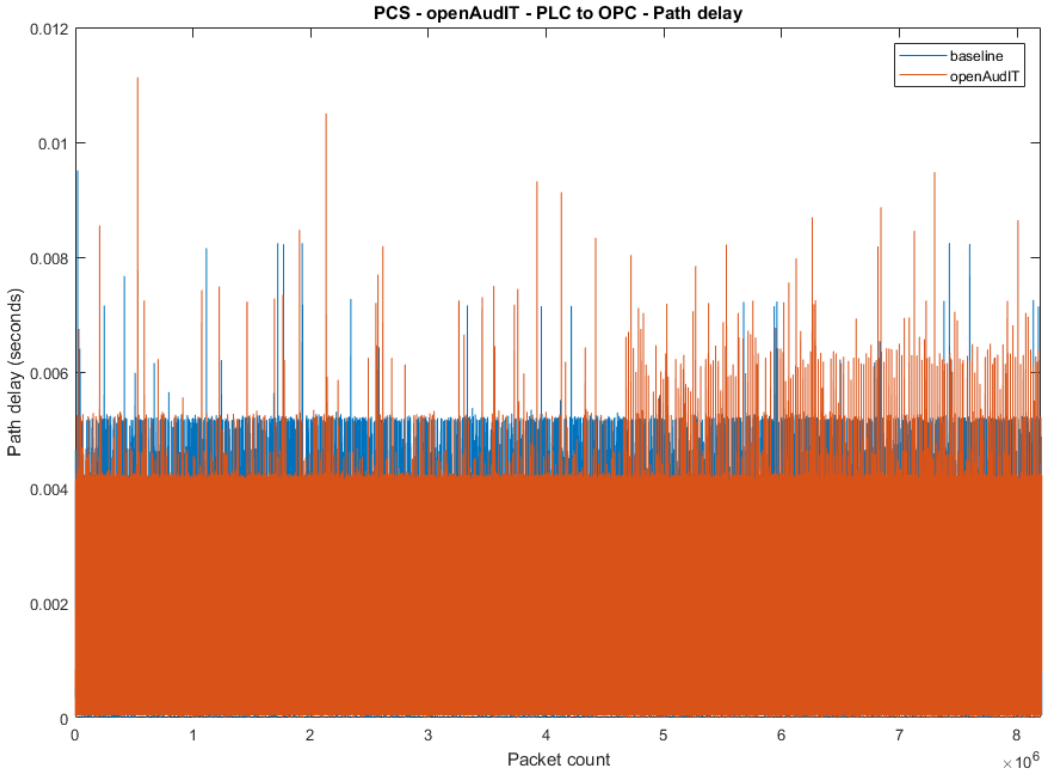


Figure 4-1 Plot showing the path delay from the PLC to OPC server

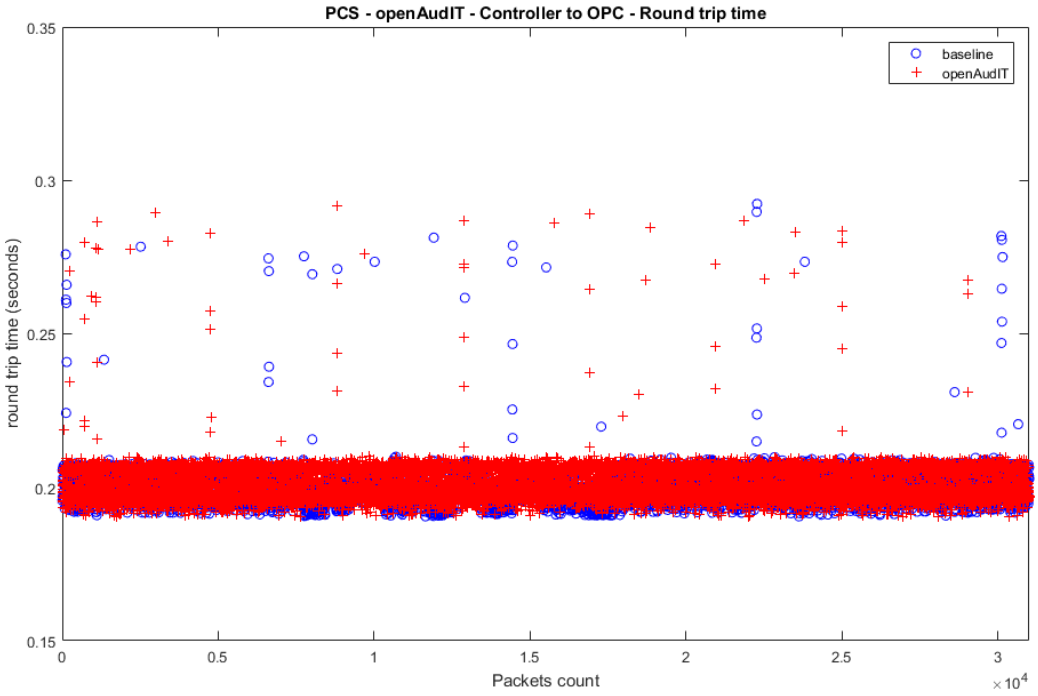


Figure 4-2 Plot of the packet round trip time from Controller to OPC

A small impact to the manufacturing process was observed. The product flow of the manufacturing process was slightly higher than the optimal level. The reactor pressure was slightly higher than the optimal level specially at the latter part of the experiment when Open-AudIT was performing the authenticated scan. However, the impact was small within the tolerance of the system.

It is hypothesized that the impacts were caused by increased network delays between the hosts of the system. There is a time delay before the network impact will start impacting the manufacturing process due to the iterative nature of the process simulation and sensor and actuator values exchange.

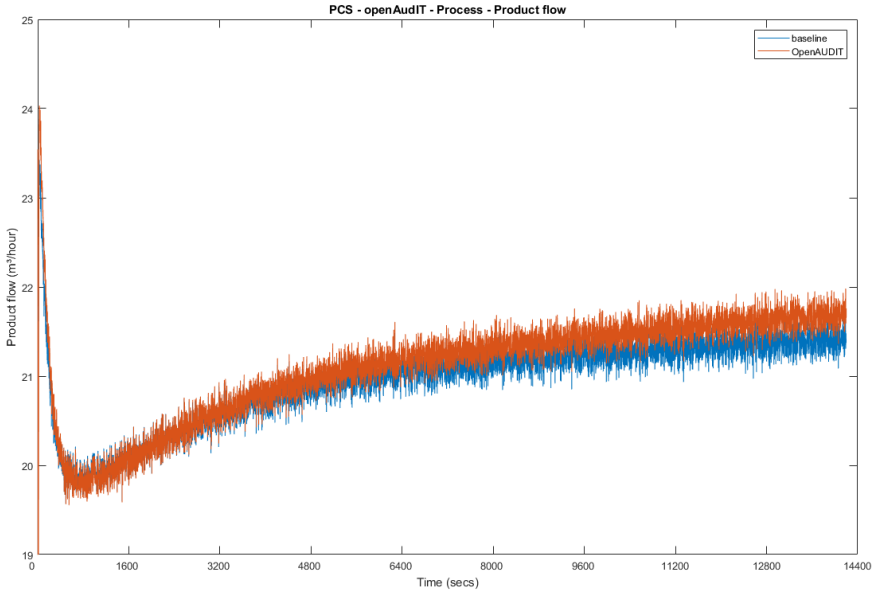


Figure 4-3 Plot of the production flow of the manufacturing process

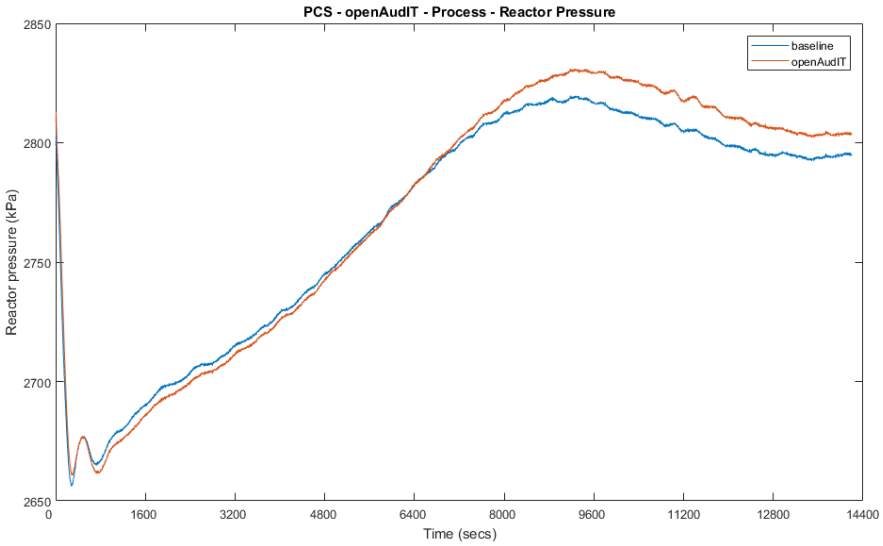


Figure 4-4 Plot of the reactor pressure of the manufacturing process

4.2.7 Links to Entire Performance Measurement Data Set

- **Open-AudIT KPI data**
- **Open-AudIT measurement data**

4.3 CSET

4.3.1 Technical Solution Overview

Cyber Security Evaluation Tool (CSET) is a tool provided by the Department of Homeland Security for performing Cybersecurity evaluation against an organization. This evaluation is a completely manual process of answering multiple questions to determine organizational cybersecurity posture based on implemented cybersecurity practices against current cybersecurity status. This evaluation will help identify areas within the organization that required more attention and resources.

4.3.2 Technical Capabilities Provided by Solution

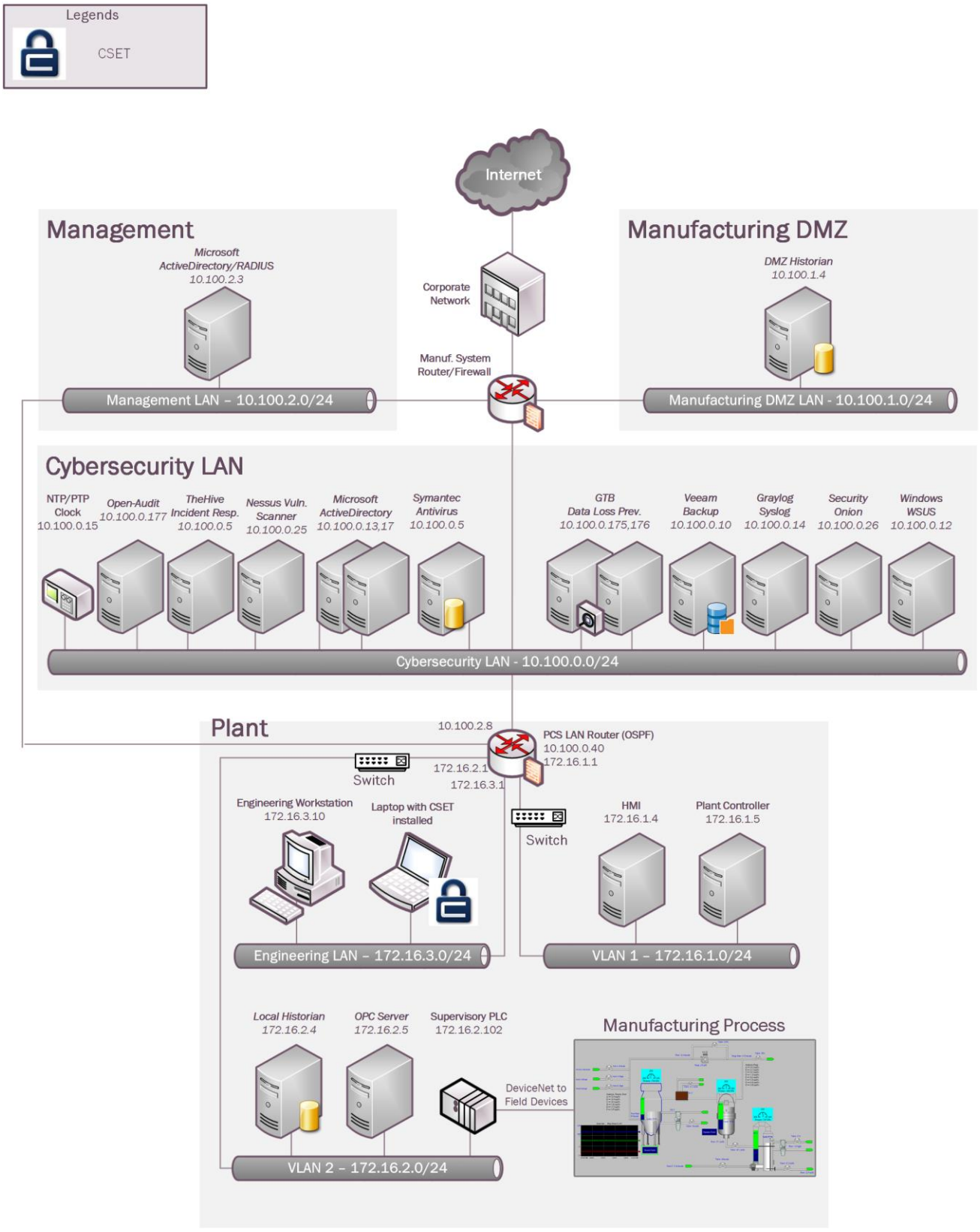
CSET provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Network Architecture Documentation
- Risk Assessment

4.3.3 Subcategories Addressed by Implementing Solution

ID.AM-3, ID.AM-4, ID.RA-1

4.3.4 Architecture Map of Where Solution was Implemented



4.3.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware Details
CSET	8.1	Laptop with the following specs: • Processor: i7 • Memory: 16 GB • Disk: 256 GB • OS: Windows 7 Professional

4.3.5.1 Environment setup

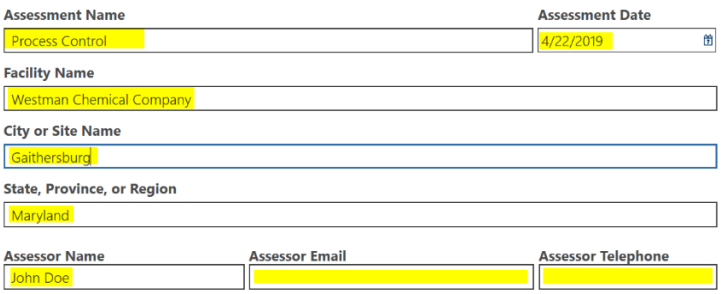
CSET was installed on a temporary Windows laptop in the plant network on an on-demand basis

4.3.5.2 Installation

1. Download CSET[58]. After clicking the link, you will be asked to identify yourself and will then be given the opportunity to download the file *CSET_x.x.**iso** (where x.x represents the download version).*
2. Use any ISO-specific utility program that can mount the file.
3. Find and run the CSET_Setup.exe file in the folder, virtual drive, or CD.
4. Complete the instructions in the installation wizard to install the program.

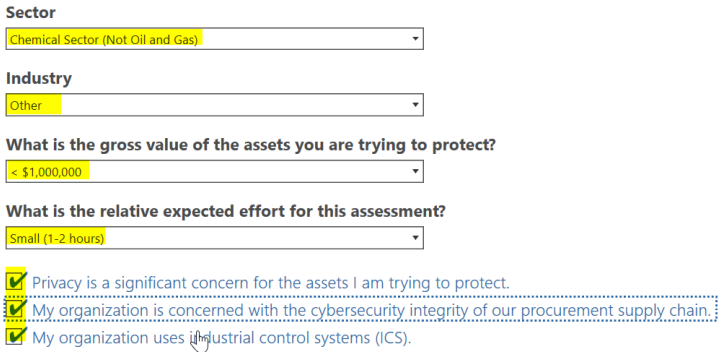
4.3.5.3 Running CSET

1. Launch the program by double-clicking its desktop icon
2. Select **New Assetment** on the home screen.
3. Click **Start Here** button in the lower right corner of program.
4. Enter all required information

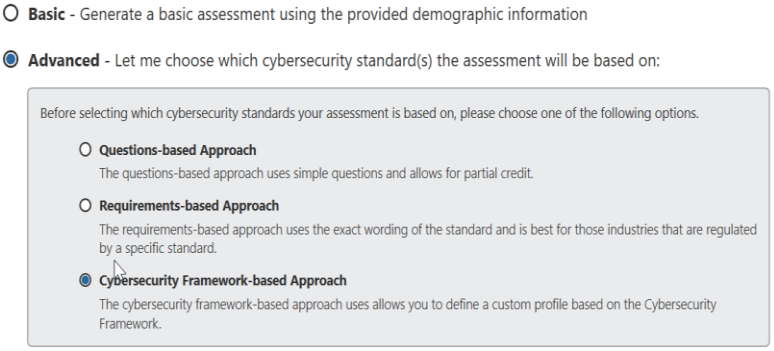


[58] https://www.us-cert.gov/forms/csetiso.

5. Click **Continue** to proceed.
6. Click the drop-down menus and select the appropriate choices.



7. Click **Continue** to proceed.
8. (Optional) Click the **Create a network diagram** button to create one, otherwise click **Continue.**
9. Change Mode Selection to **Advanced** and **Cybersecurity Frame-based Approach**



10. Click **Continue** to use default profile or create a new profile.
11. Click **Continue** again.
12. Answer all the questions as they appear.
13. Complete all questions and generate a final report.

4.3.5.4 Additional Information

Video tutorials[59] are available on the CSET YouTube Channel to help you better understand how to use this tool.

Lessons Learned

- The tool is only as good as information entered. Make sure each answer is thought out before answering.
- Mark any answer for review as needed so there will be follow up.
- When completed your organization will receive a 0 to 100 score depending on readiness.

4.3.6 Highlighted Performance Impacts

No performance measurement experiments were performed for CSET due to its typical installation location (i.e., external to the manufacturing system).

4.3.7 Links to Entire Performance Measurement Data Set

N/A

[59] https://www.youtube.com/c/CSETCyberSecurityEvaluationTool

4.4 GRASSMARLIN

4.4.1 Technical Solution Overview

GRASSMARLIN is an open source, passive network mapper dedicated to industrial networks and developed by the National Security Agency (NSA). GRASSMARLIN gives a snapshot of the industrial system including:

- Devices on the network
- Communications between these devices
- Metadata extracted from these communications

Points to consider:[60]

- Passive IP network mapping tool
- Hardware agnostic portable Java based tool
- Can only see and map hosts where you are capturing data from.

4.4.2 Technical Capabilities Provided by Solution

GRASSMARLIN provides components of the following Technical Capabilities described in Section 6 of Volume 1:

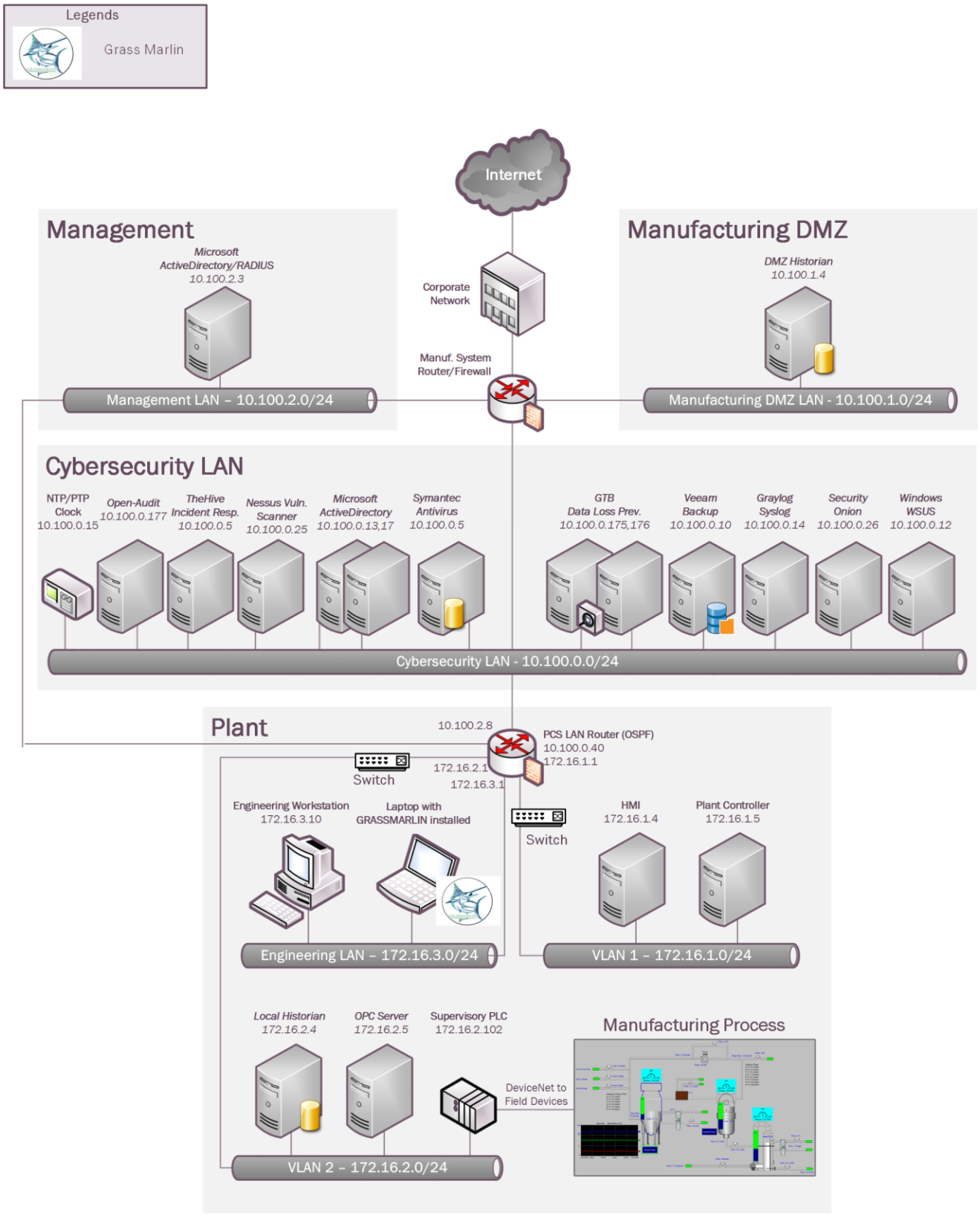
- Network Architecture Documentation
- Baseline Establishment
- Map Data Flows

4.4.3 Subcategories Addressed by Implementing Solution

ID.AM-3, ID.AM-4, PR.AC-5, PR.IP-1, DE.AE-1, DE.CM-7

[60] GRASSMARLIN Briefing PowerPoint 2017: https://github.com/nsacyber/GRASSMARLIN /blob/master/GRASSMARLIN_Briefing_20170210.pptx

4.4.4 Architecture Map of Where Solution was Implemented



4.4.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware Details
GRASSMARLIN	3.2.1	Laptop with the following specs: • Processor: i7 • Memory: 16 GB • Disk: 256 GB • OS: Windows 7 Professional

4.4.5.1 Environment Setup

1. A temporary Windows laptop with GRASSMARLIN installed was setup in the plant network on an on-demand basis.

4.4.5.2 Installation

1. Download GRASSMARLIN[61]
2. Run the installer. The installer will install additional programs such as Java and Wireshark during the setup.

4.4.5.3 Using the Software

GRASSMARLIN can operate in a real time passive mode by sniffing the live traffic or by importing a recorded pcap file. Data in GRASSMARLIN is stored in a Session. The Session contains imported files and visual state information.

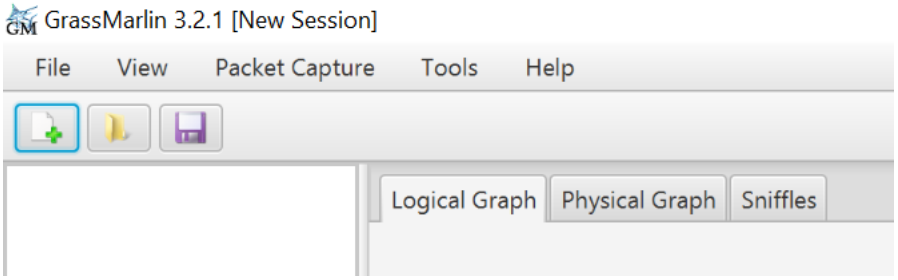
1. To capture network packets & save to a pcap file on a Linux system
   a. Install **tcpdump** package if not present already
   b. Run, `tcpdump -i <mirror-port interface> - w mypcap.pcap`
      For example: `tcpdump -i eth1 -w /home/icssec/pcs.pcap`
      Where `eth1` is the span / mirror port connection

2. Run GRASSMARLIN on a Windows system by double clicking the program icon from the Programs Menu. On a Linux system, run `sudo grassmarlin` to launch the installer.

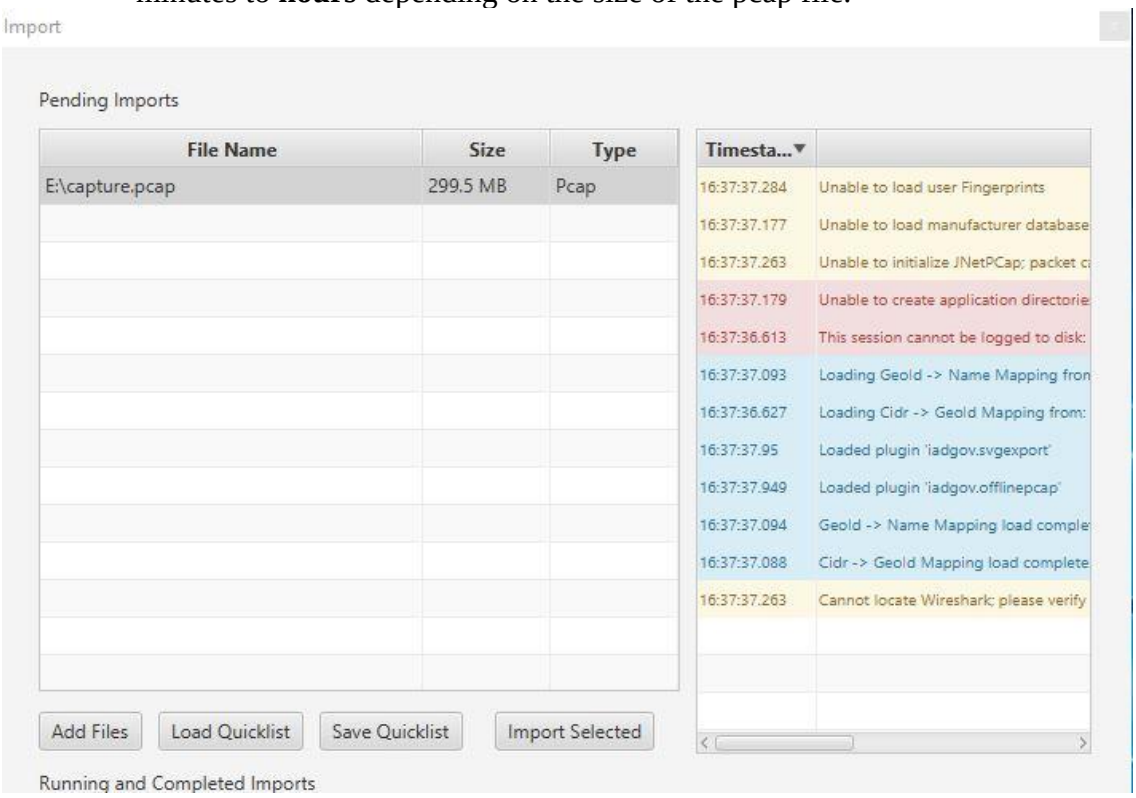
[61] https://github.com/nsacyber/GRASSMARLIN/releases

3. Import a pcap in GRASSMARLIN as follows:

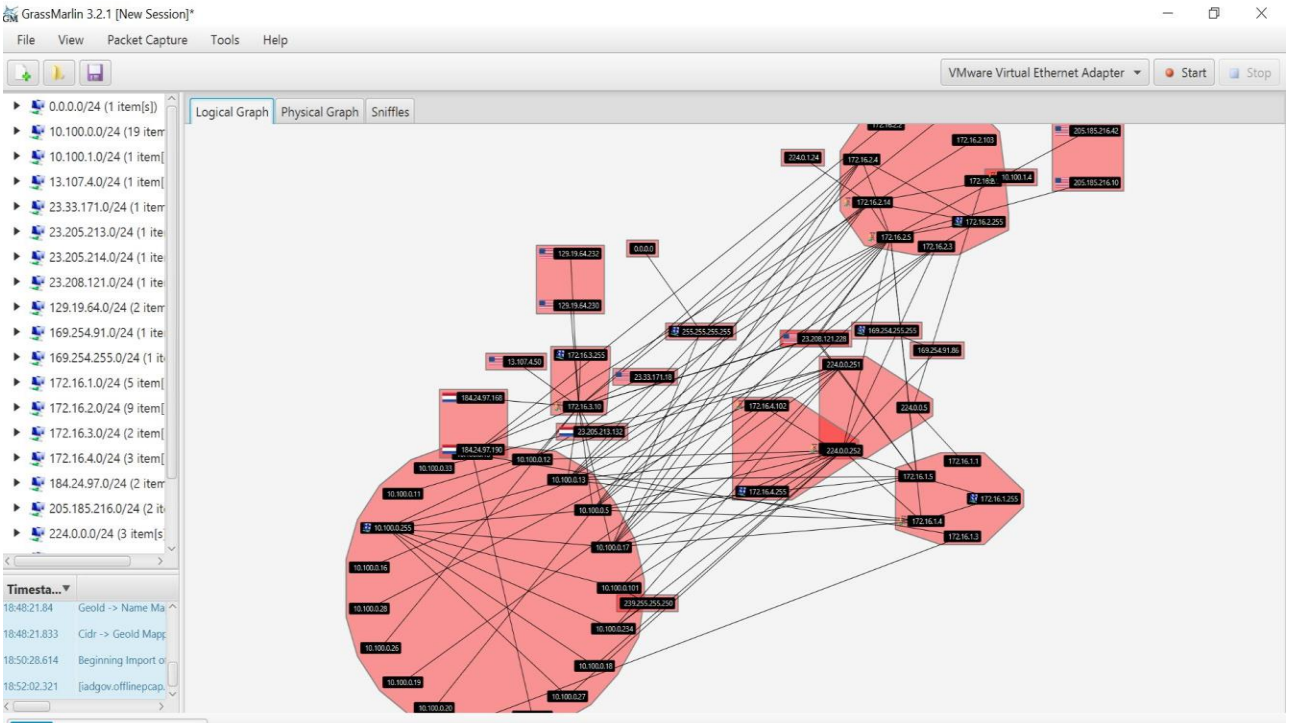
   - Click on the **Import** icon in the toolbar (or select **Import files** from the File Menu)



   - Click on **Add Files.** Browse to the pcap file. Once done, the pcap will now show up under **Pending Imports**.
   - Select the file and click on **Import Selected.** Hit the **Close** button upon completion to back to the Main interface. The Import process can take several minutes to **hours** depending on the size of the pcap file.

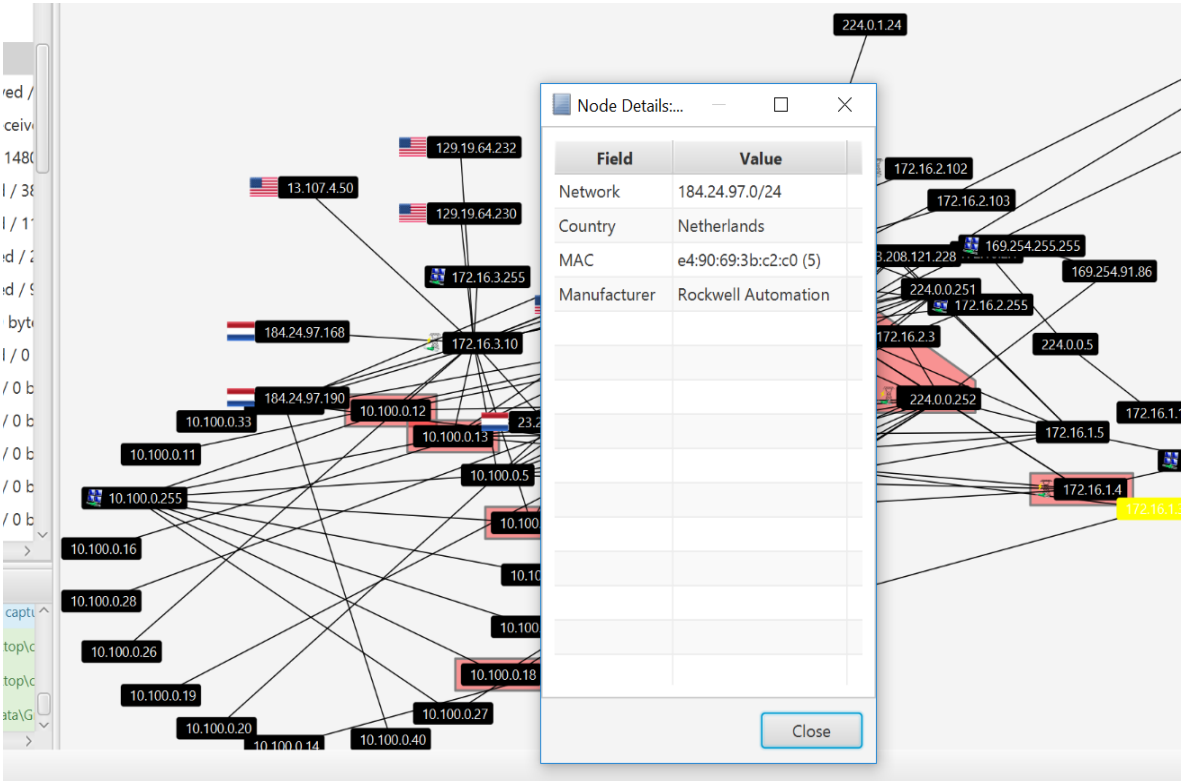


Upon the completion of **Import**, the main screen will display a Logical Graph of the network topology as shown below.

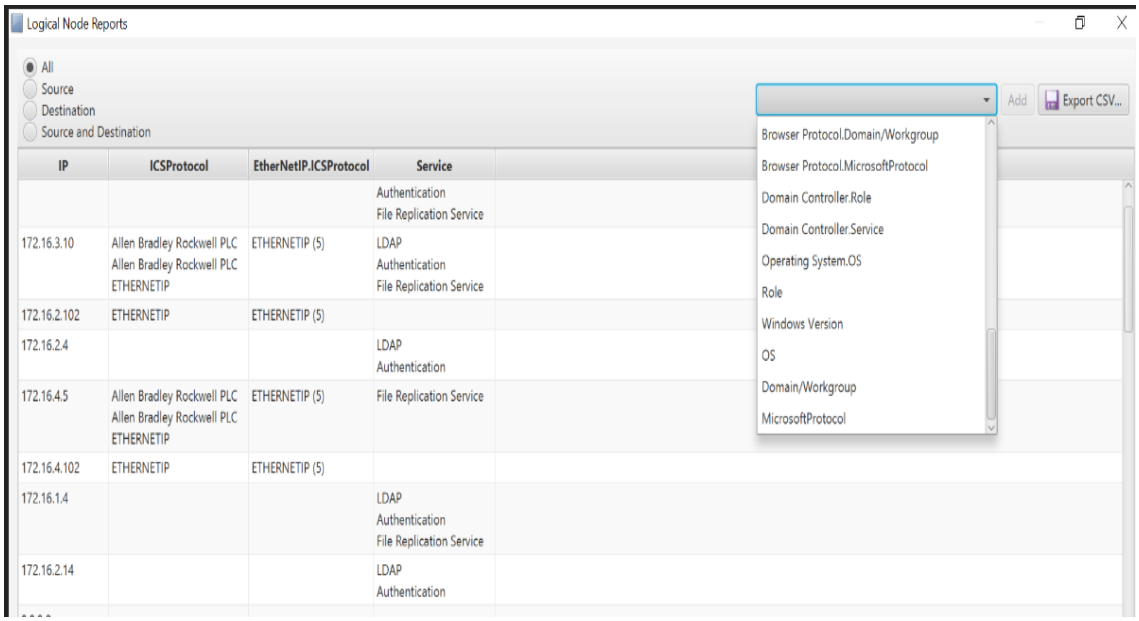


4. Review the logical graph. All public IP addresses will also be highlighted with their respective country's flag. This can be useful in finding out information about any external IPs that your network is communicating with.

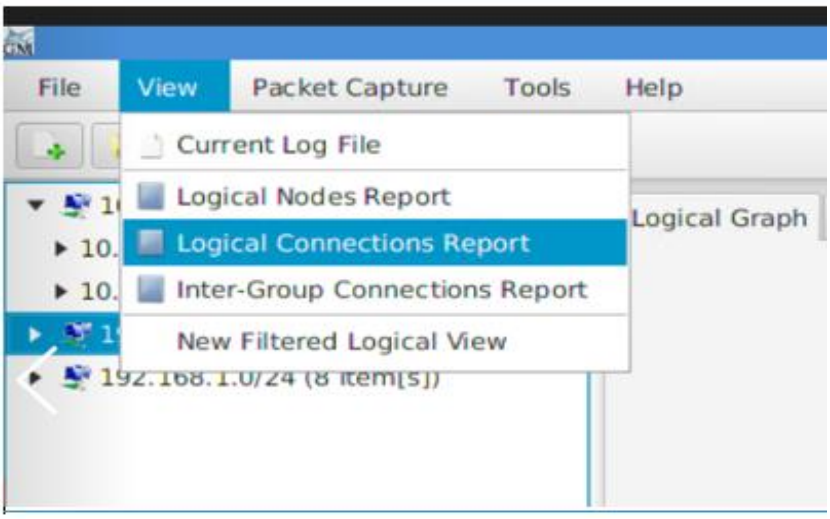
5. Right-click any external IP address > **View Details**. For instance, the image below shows a host with IP 172.16.3.10 communicating with an IP address from Netherlands.



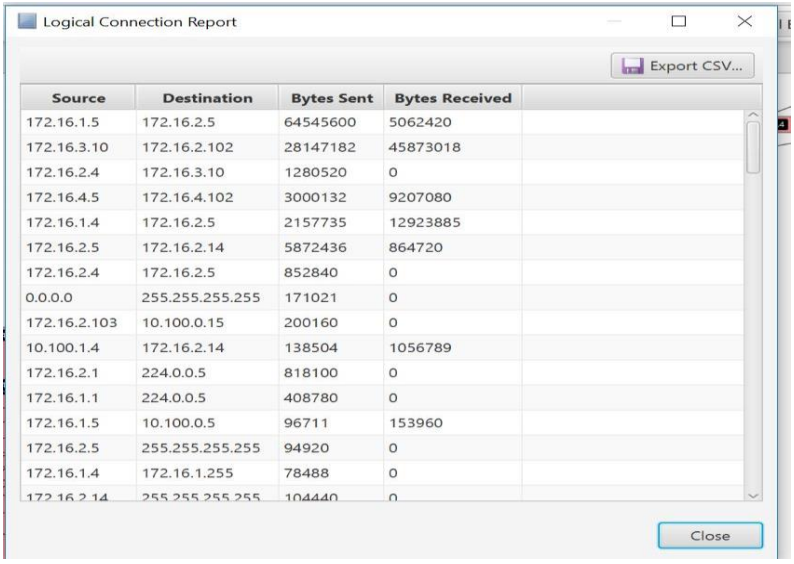
6. Generate a list of all nodes in the Logical Graph as follows:
    a. Click **View** (Top Menu) > **Logical Nodes Report.**
    By default, only a single column (IP) is present, although additional columns can be added with any Property present in the set of Nodes.
    b. Select any Property Name from the drop-down and click **Add** button to add new Columns in the Report.



7. Generate a report of all connections in the pcap file as follows:
    a. Click **View** (Top Menu)>> **Logical Connections Report**.

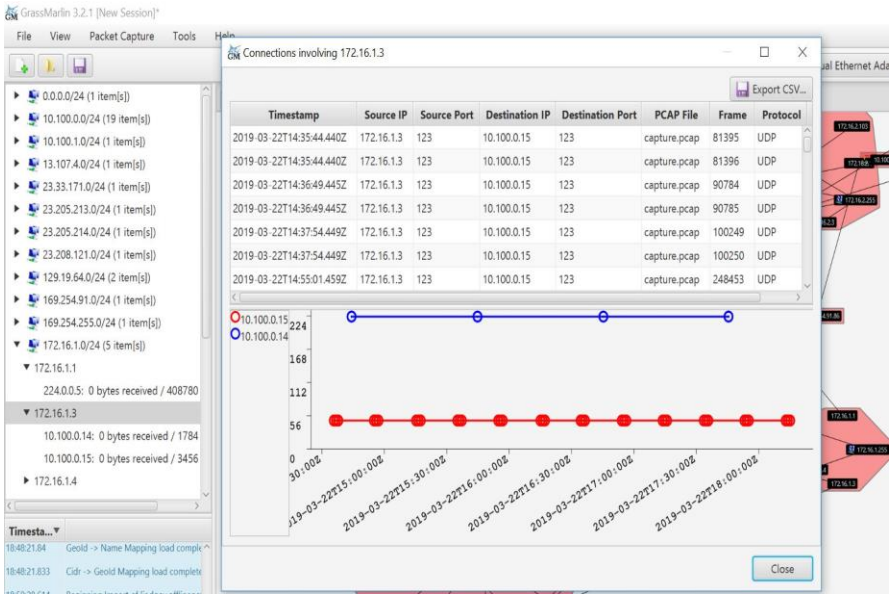


b. Click on **Export CSV** for further analysis of all the communications happening on your network. This will generate an output similar to the image show below.

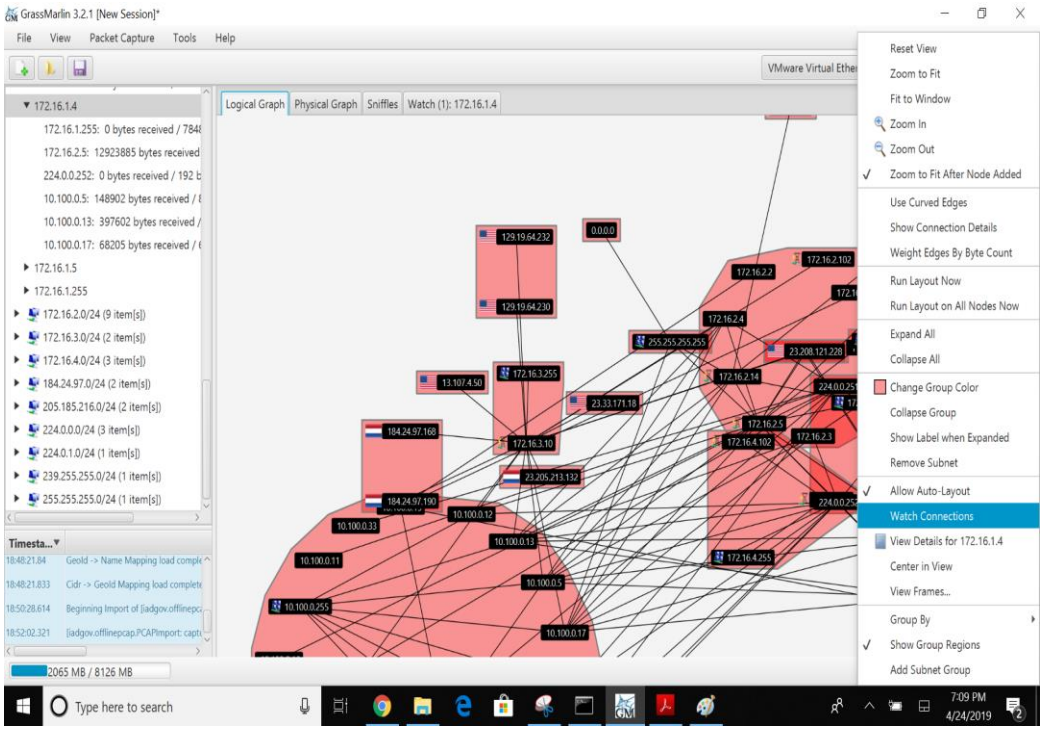


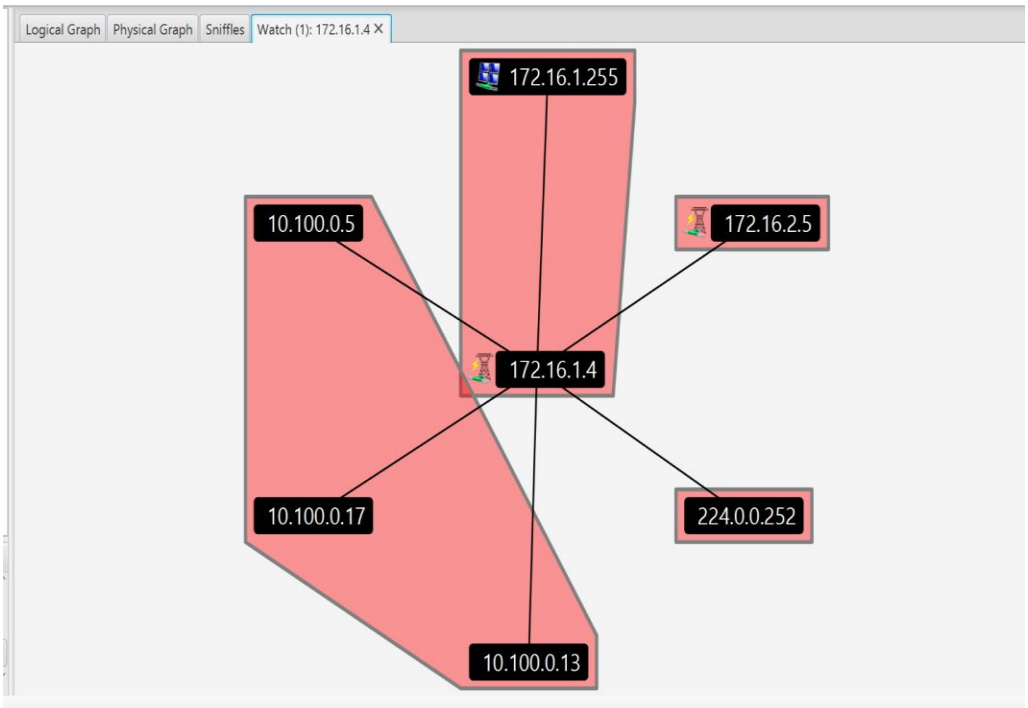
Source	Destination	Bytes Sent	Bytes Received
172.16.1.5	172.16.2.5	64545600	5062420
172.16.3.10	172.16.2.102	28147182	45873018
172.16.2.4	172.16.3.10	1280520	0
172.16.4.5	172.16.4.102	3000132	9207080
172.16.1.4	172.16.2.5	2157735	12923885
172.16.2.5	172.16.2.14	5872436	864720
172.16.2.4	172.16.2.5	852840	0
0.0.0.0	255.255.255.255	171021	0
172.16.2.103	10.100.0.15	200160	0
10.100.1.4	172.16.2.14	138504	1056789
172.16.2.1	224.0.0.5	818100	0
172.16.1.1	224.0.0.5	408780	0
172.16.1.5	10.100.0.5	96711	153960
172.16.2.5	255.255.255.255	94920	0
172.16.1.4	172.16.1.255	78488	0
172.16.2.14	255.255.255.255	104440	0

8. To view all the logical communications for a specific host for capturing a baseline:
   a. Right-click on a **Node** > **View Frames**.
      This opens a new screen as shown below displaying all the different IP addresses that particular host is communicating with including Port and Protocol information.
   b. Click on **Export CSV** button to export this data to a csv file.
      Note: This process needs to be repeated for every node.



9. Generate a Watch -Graph as follows:
   a. Right-click a **node** > Select **Watch Connections** from the **Watch Connections** menu.
   This will generate a graph in a new window **Watch <IP address>**





4.4.5.4 Additional Information

A User guide[62] is available for GRASSMARLIN.

4.4.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the use of GRASSMARLIN due to its installation location and how it was used (i.e., the software performed offline analysis of PCAP files captured by other software).

4.4.7 Links to Entire Performance Measurement Data Set

N/A

[62] https://github.com/nsacyber/GRASSMARLIN

4.5 Wireshark

4.5.1 Technical Solution Overview

Wireshark is a free and open-source packet analyzer.

4.5.2 Technical Capabilities Provided by Solution

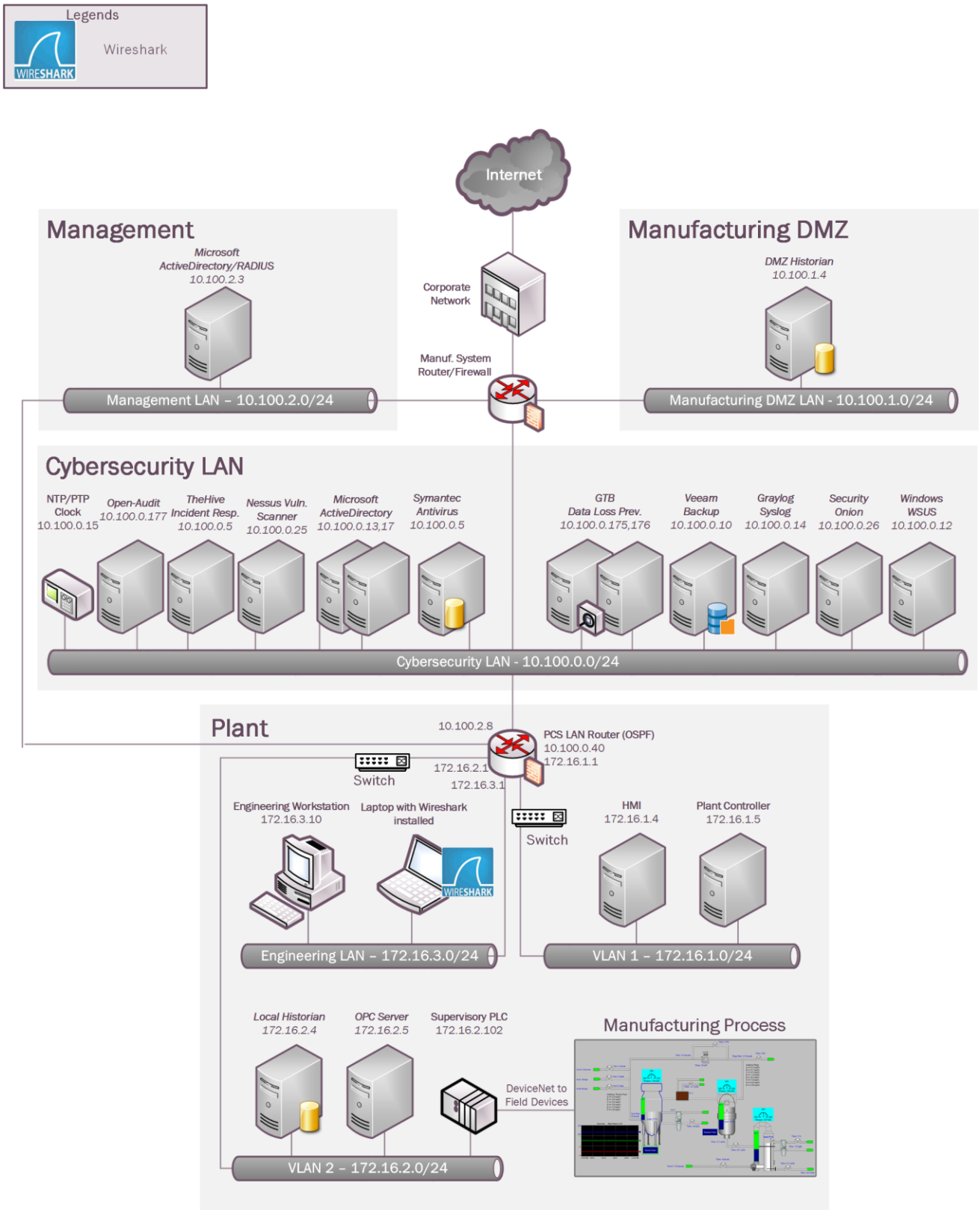
Wireshark provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Network Architecture Documentation
- Baseline Establishment
- Map Data Flows
- Forensics

4.5.3 Subcategories Addressed by Implementing Solution

ID.AM-3, ID.AM-4, PR.AC-5, PR.IP-1, DE.AE-1, DE.AE-2, DE.CM-7, RS.AN-3

4.5.4 Architecture Map of Where Solution was Implemented



4.5.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware Details
Wireshark	3.0.2	Laptop with the following specs. • Processor: i7 • Memory: 16 GB • Disk: 256 GB • OS: Windows 7 Professional

4.5.5.1 Environment Setup

A Windows laptop with Wireshark installed was setup on an on-demand basis.

4.5.5.2 Installation

1. Download Wireshark[63] **(Select 32bit or 64 bit)**
2. Run the exe to start install process. For instance, *Wireshark-win64-3.0.1.exe*
3. Click **Next**, leave the defaults selected and continue install.
4. Click **I Agree** to continue, when prompted for Npcap install
5. Now click **Next and Finish** to start process.
6. Select **Reboot Now** or **I want to manually reboot later.**
7. Click **Finish** to complete.

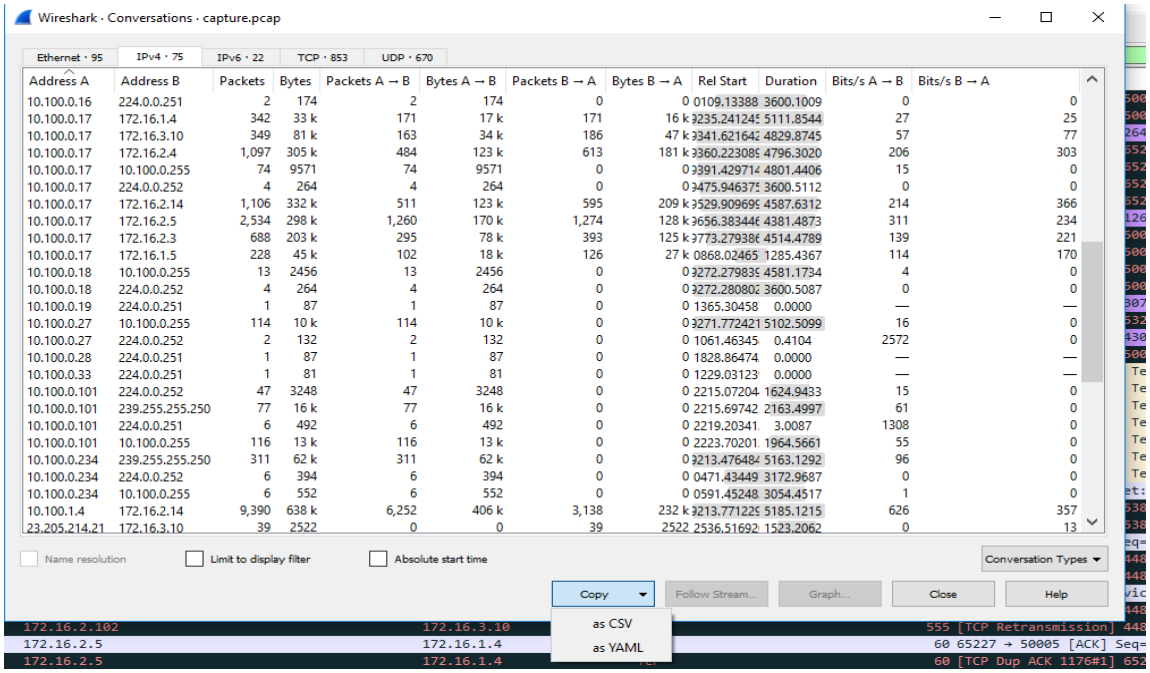
4.5.5.3 Running Wireshark

1. Launch Wireshark by doing a right-click on the Wireshark Desktop icon > **Run as Administrator (Windows 10).** Wireshark requires administrative privileges to be fully functional, otherwise there will be undesired results.
2. Select the interface to capture traffic from the list of interfaces displayed

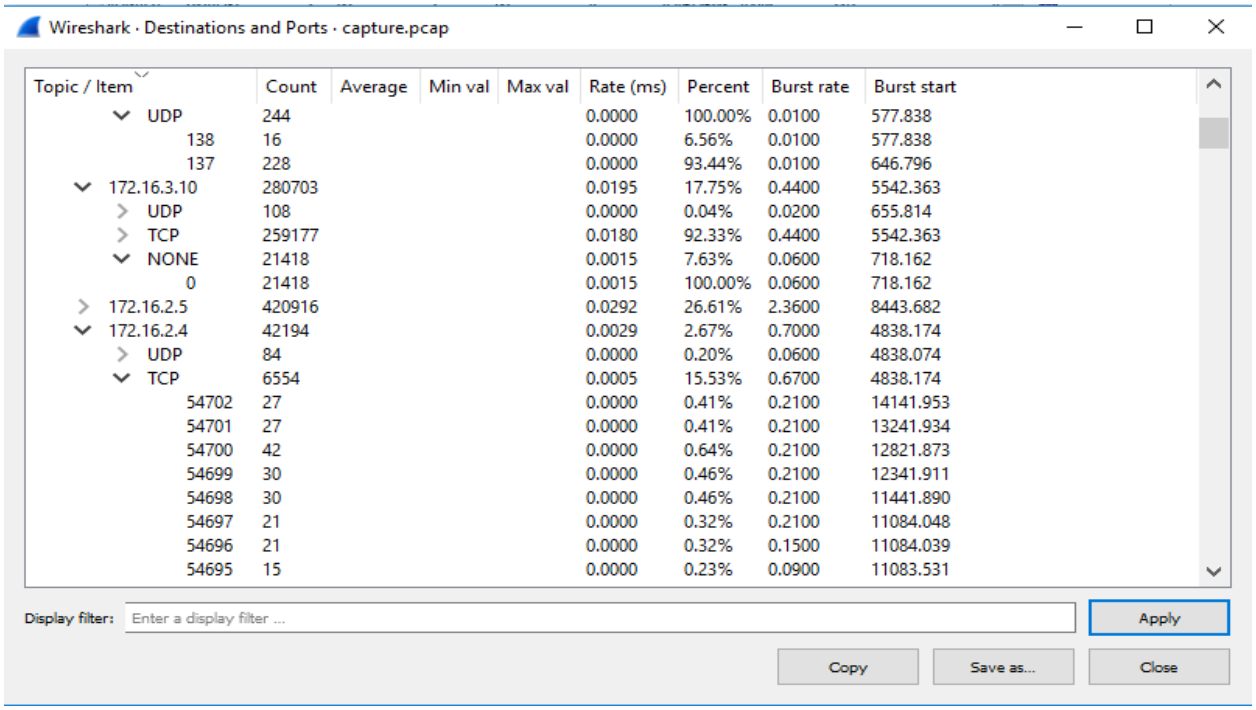
[63] https://www.wireshark.org

4.5.5.4 Capturing Network Baseline using Wireshark

1. Click **Open** to load a previously captured pcap file or run a **Start Capture**
2. Click on **Statistics** > **Conversations** upon loading the pcap or capturing live traffic.
3. Click **COPY** > **as Csv** to save this data as a Csv file for further analysis. Screenshot shown below for reference



4. (Optional) Click on **Statistics** > **IPv4 Statistics** > **Destination and Ports** to get a list of all the ports**.** This will generate a list of ports used by all the IP addresses in the traffic. Click **Copy**, to copy the results to a word document or click **Save as** to save as a plain text file. Hit **Close** when done.



4.5.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Wireshark tool while the manufacturing system was operational:

Experiment PL015.2-wireshark

Significant performance impact on computing resources was observed when using Wireshark for network traffic capture. Both the processor and memory utilization of the host were significantly higher than normal. There was no performance impact to the manufacturing process observed.

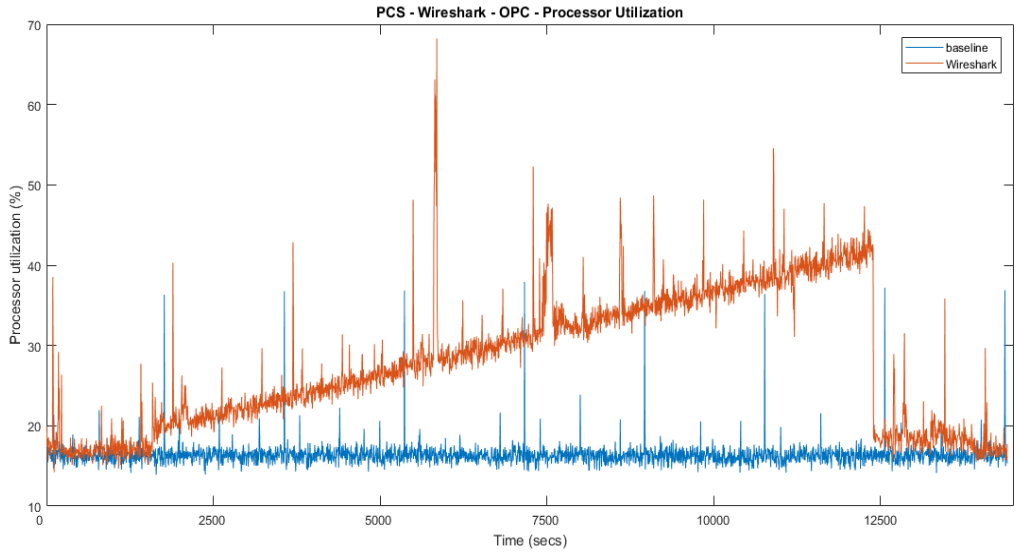


Figure 4-5 Processor utilization of the OPC computer during Wireshark network capture

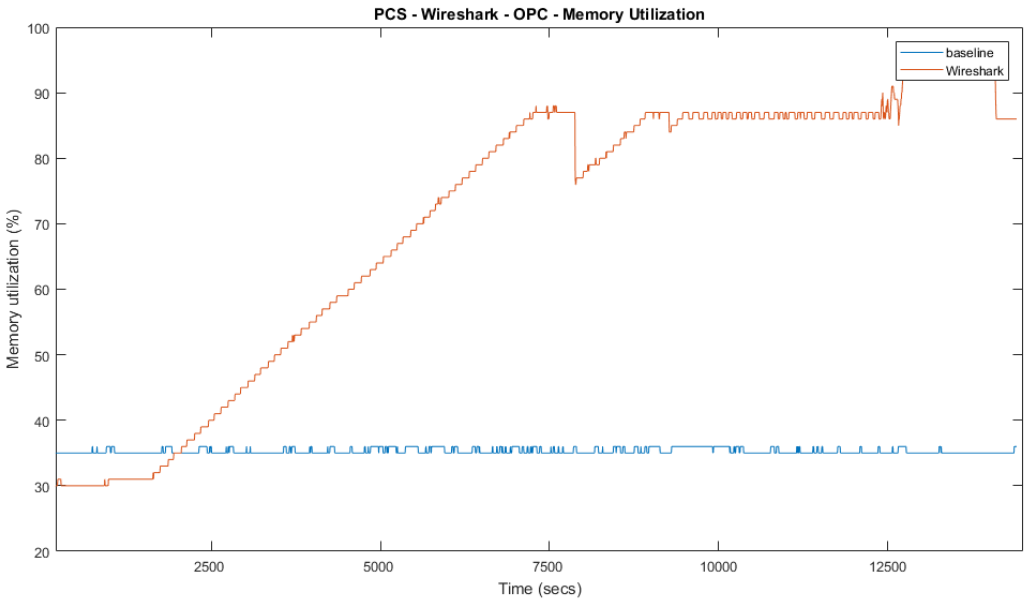


Figure 4-6 Memory utilization of the OPC computer during Wireshark network capture

Wireshark started at around 1900 seconds experiment time and continued to capture network traffic for about 3 hours. During this period of time, the processor utilization of the OPC computer kept going up. Wireshark has a sizeable impact to the processor utilization. The Wireshark data file was about 2.3 GB in this case.

The memory utilization has a similar impact to the processor utilization, except the memory utilization stayed high after the Wireshark has stopped capturing the network traffic. It is hypothesized that Wireshark stored the captured data in memory until the data was saved into the hard drive. Therefore, the memory utilization stayed high even after the Wireshark has stopped the network capture. Even though the processor and memory utilization were significantly higher, they were still below the full capability of the computer and therefore did not have major impact to the manufacturing process. However, for the manufacturing system that has a high utilization in normal run time, the use of Wireshark may cause a performance impact.

The PCS system uses an external computer to use Wireshark to perform network traffic capture for this reason. Care should be taken if using Wireshark on a production system.

4.5.7 Links to Entire Performance Measurement Data Set

- **Wireshark KPI data**
- **Wireshark measurement data**

4.6 Veeam Backup and Replication

4.6.1 Technical Solution Overview

Veeam Backup and Replication[64] is a proprietary backup and system recovery software developed by Veeam for virtual environments. It is built on VMware vSphere and Microsoft Hyper-V hypervisors. The software provides backup, restore and replication functionality. Veeam also has products such as "Veeam agent for Windows" and "Veeam agent for Linux" for backing up physical Windows and Linux servers respectively.

Points to consider:

- Free backup edition available for virtual and physical servers.
- Support for file level backups as well as system image type of backups.
- Backups can be run without having to shut down the system. This can be very critical in manufacturing environments.
- Tech support available for Free edition users.
- Easy to setup and use.

4.6.2 Technical Capabilities Provided by Solution

Veeam Backup and Replication provides components of the following Technical Capabilities described in Section 6 of Volume 1:

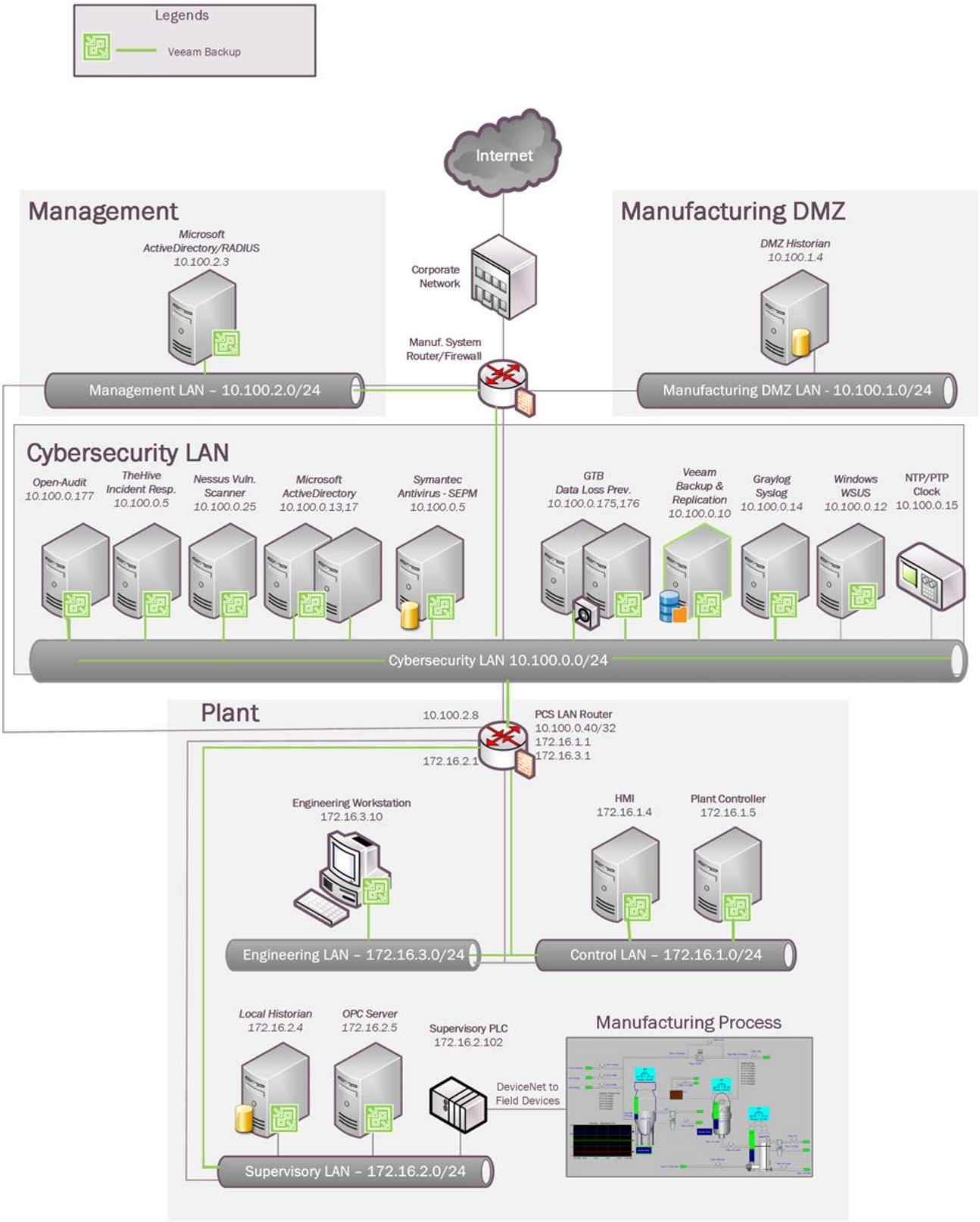
- Data Backup
- Data Replication

4.6.3 Subcategories Addressed by Implementing Solution

PR.IP-4

[64] https://www.veeam.com/vm-backup-recovery-replication-software.html

4.6.4 Architecture Map of Where Solution was Implemented



4.6.5 Installation Instructions and Configurations

Details of the solutions implemented:

Name	Version	Hardware Details
Veeam Backup and Replication	9.5	VMware Virtual Machine • Processors: 2 virtual cores • Memory: 8 GB • Disk space:4 TB. • Network: 1 interface • Operating System: Windows 2012R2
Veeam Agent for Windows (Free version)	3.0.0.748	Installed on all Physical Windows computers of the plant

4.6.5.1 Environment Setup

1. A virtual machine running Windows 2012 R2 was setup with hardware specifications as described in the table above.
2. The guest OS IP information was set as follows:

```
IP address: 10.100.0.10
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

3. A **backups** network share was created on the server. Within this folder, different sub folders were created as per the hostnames of each system to be backed up. Each system's backup job was in turn configured to be saved to its corresponding hostname folder on the Veeam server via a UNC path
4. A user account **veeamuser** was created in our Active Directory and assigned read/write permissions for the above backups share.

4.6.5.2 Initial Setup

1. Download **Veeam Backup & Replication**[65]
2. Install the prerequisites as mentioned in the product guide. Run the installer, follow the on-screen instructions to complete the install[66].
3. Create a network share folder on the Veeam server for storing all the backups.
4. Create a Service account in Active Directory with read/write permissions to this network share.

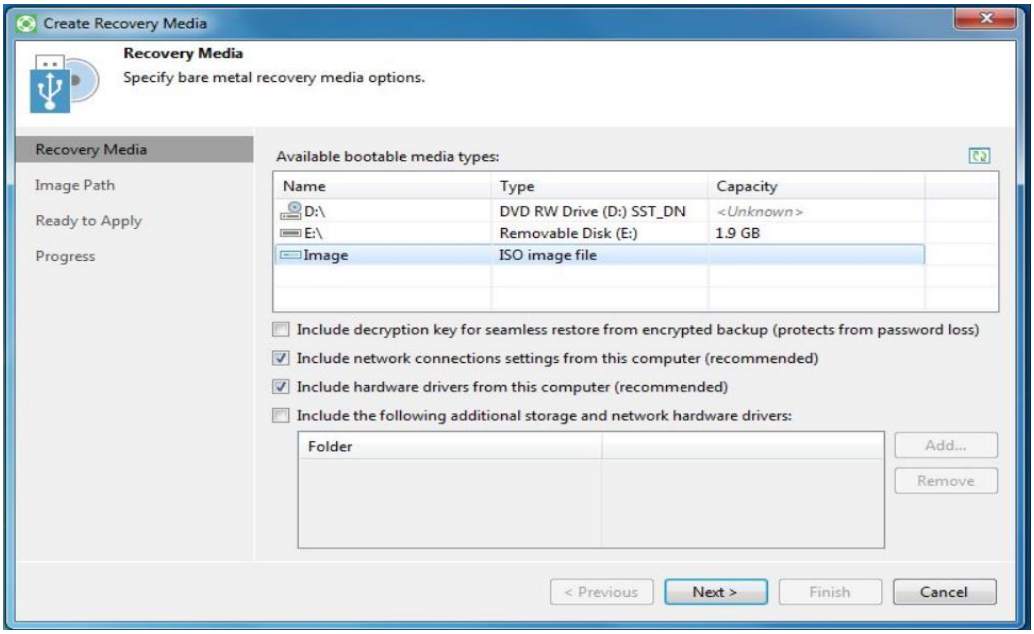
[65] https://www.veeam.com
[66] https://helpcenter.veeam.com/docs/backup/hyperv/install_vbr.html?ver=95u4

The Free Edition of Veeam Backup and Replication lets you manage virtual machine backups from the Central Veeam Backup and Replication Console. However, any physical servers using the Free version of Veeam agent for Windows cannot be managed from the Central console. These need to be managed locally from the client system itself.

4.6.5.3 Performing Backups

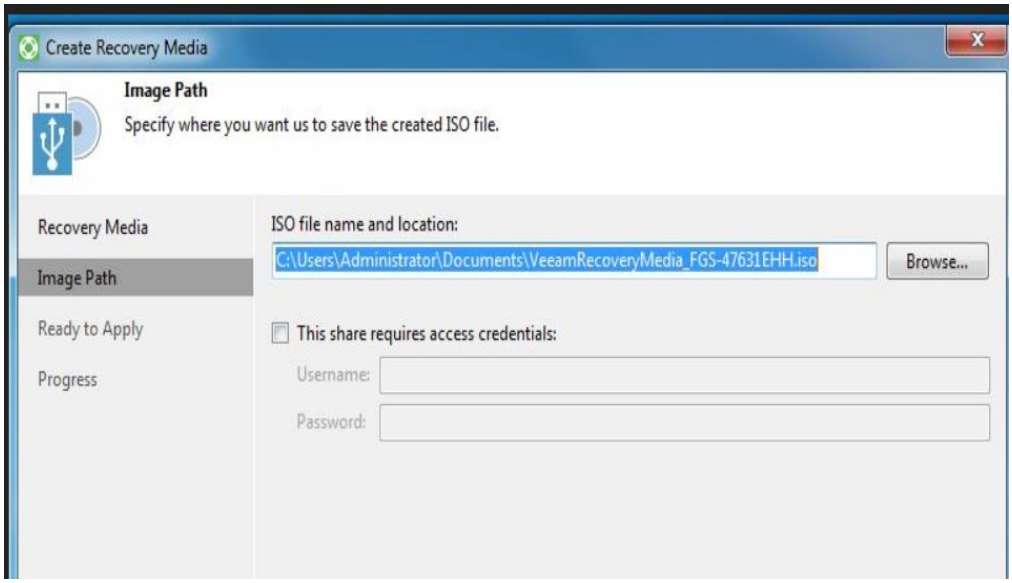
All Windows systems of the plant network were configured for Backup using Veeam Agent for Windows[67]. The agent was installed on all the physical windows clients. Connectivity between each client and the Veeam Server was verified by accessing the **backups** share folder (created in the above section) from each client.

1. Download and install Veeam Agent for Microsoft Windows on the physical Windows systems as required. In the Free version, a backup or restore operation needs to be initiated from the client system.
2. Double click the **Veeam backup icon** in the System tray to launch the wizard
3. Create a **Recovery Media** as follows
    a. Follow the on-screen prompts during the setup to create one OR
    b. Run **Veeam.Endpoint.RecoveryMedia.exe** program under **C:\Program Files\Veeam\Endpoint Backup** directory to create one manually.
    c. Select **ISO** image file under **Available Bootable Media Types**



[67] https://www.veeam.com/windows-endpoint-server-backup-free.html

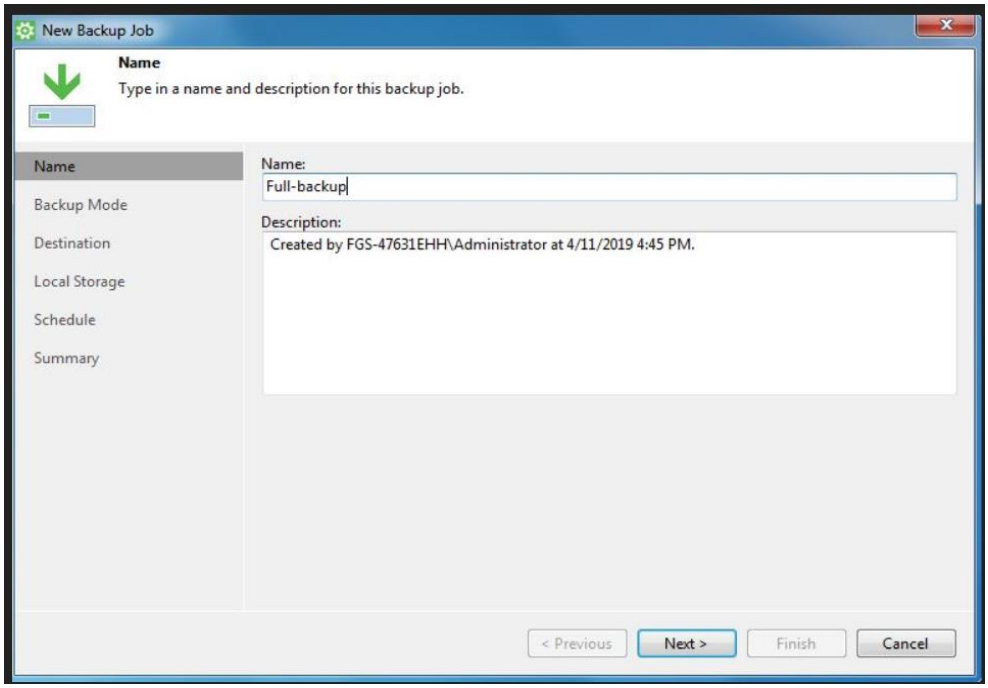
d. Enter the Name and Location to save the ISO.



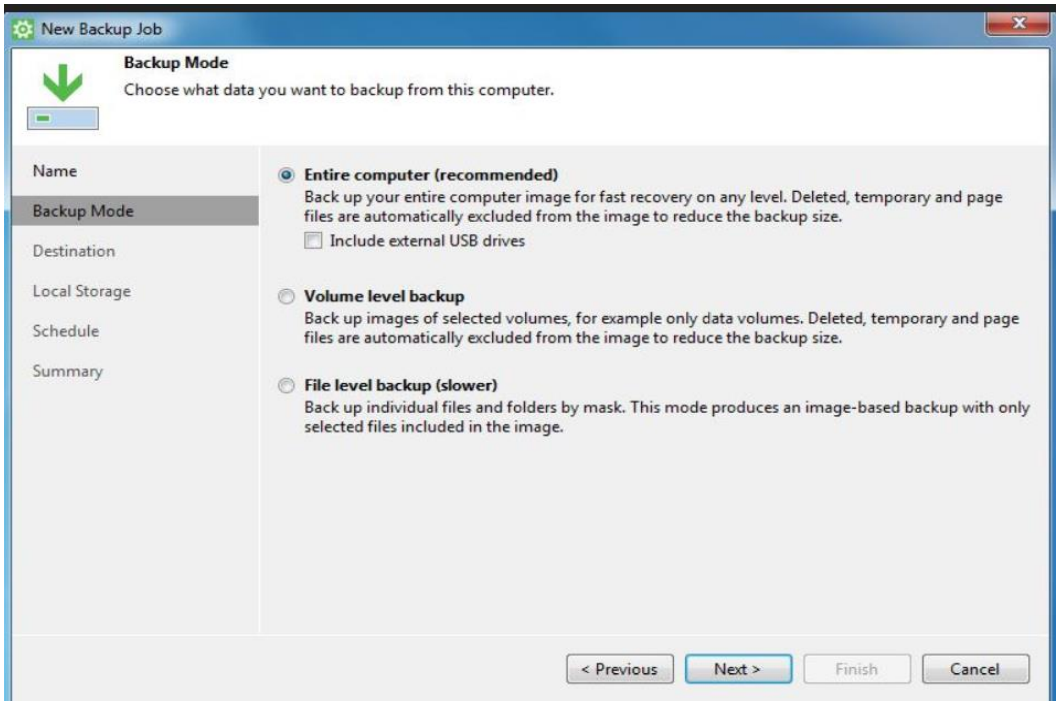
This Recovery Media is required for Recovery operations involving Full Computer Image or Volume level backup.

4. To perform a backup of **Entire Computer** type (System Image)

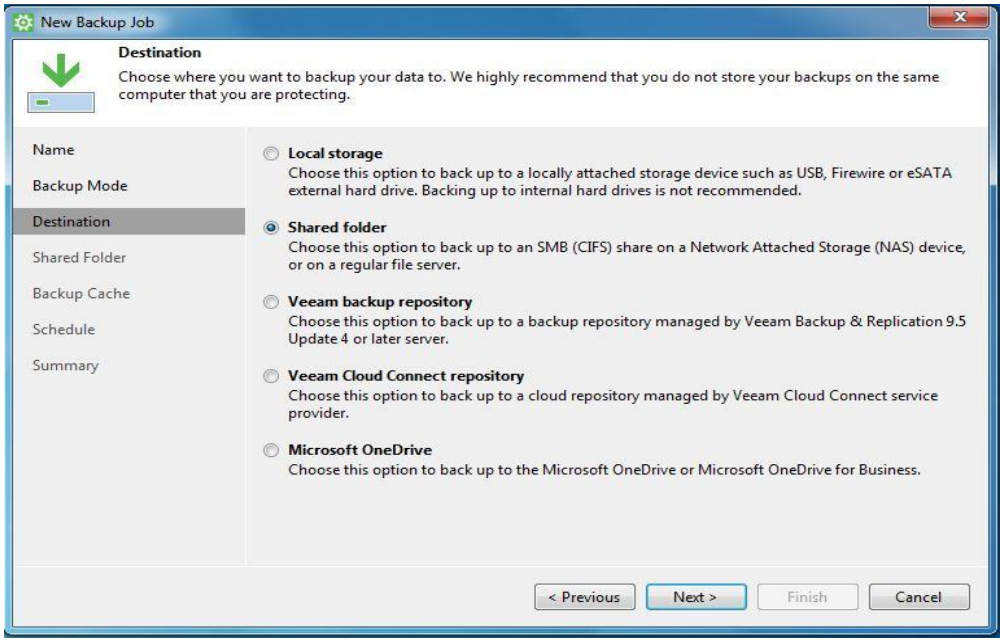
   a. Right-click on the Veeam Tray, select **Control Panel > Backup > Add New Job**
   b. Enter the name of the Backup job



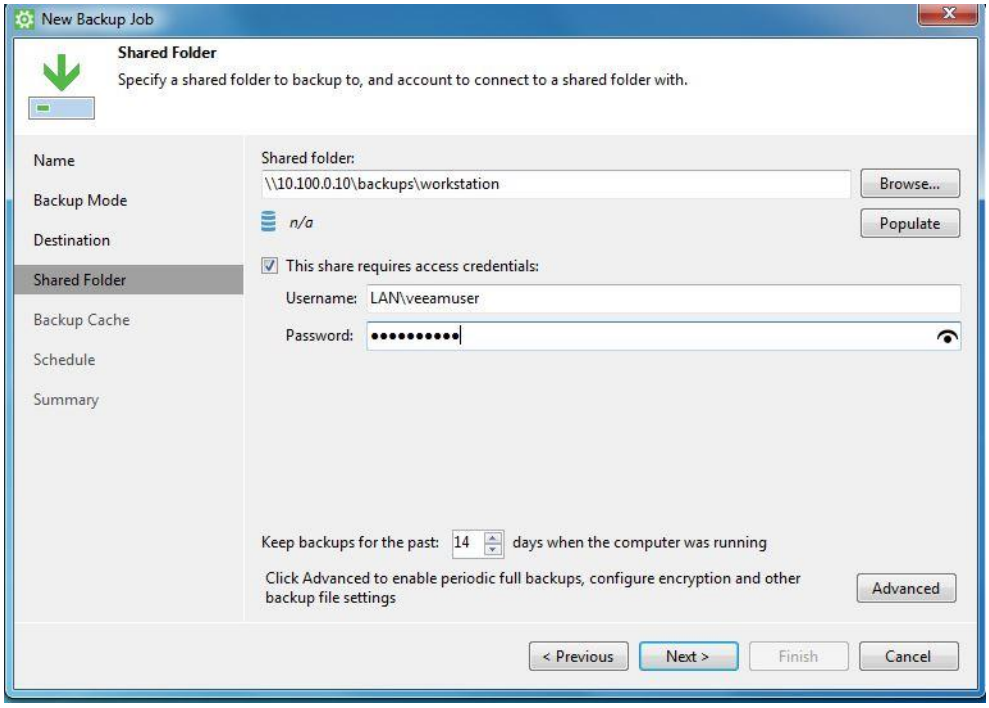
c. Select **Entire Computer** as the **Backup Mode**



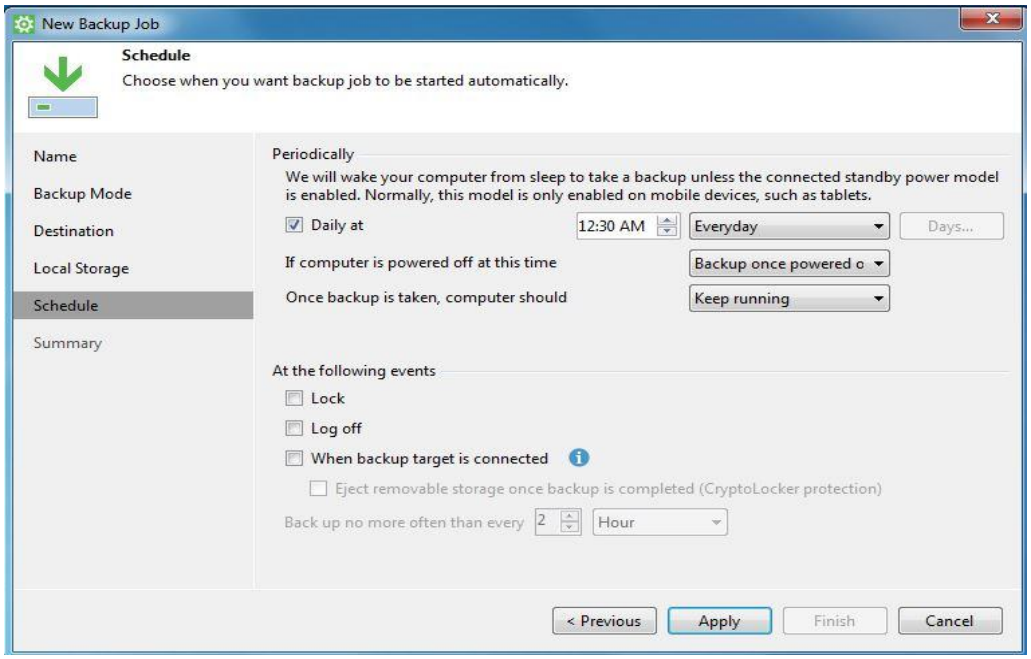
d. Select a Backup Destination. Choose **Shared folder** if saving the backups to a network share as in our case.



e. Enter the path of the Network share and the Active Directory user credentials created earlier. Select the Number of Restore Points as per your retention policy.



f. Configure a Schedule. Hit **Apply** when done.

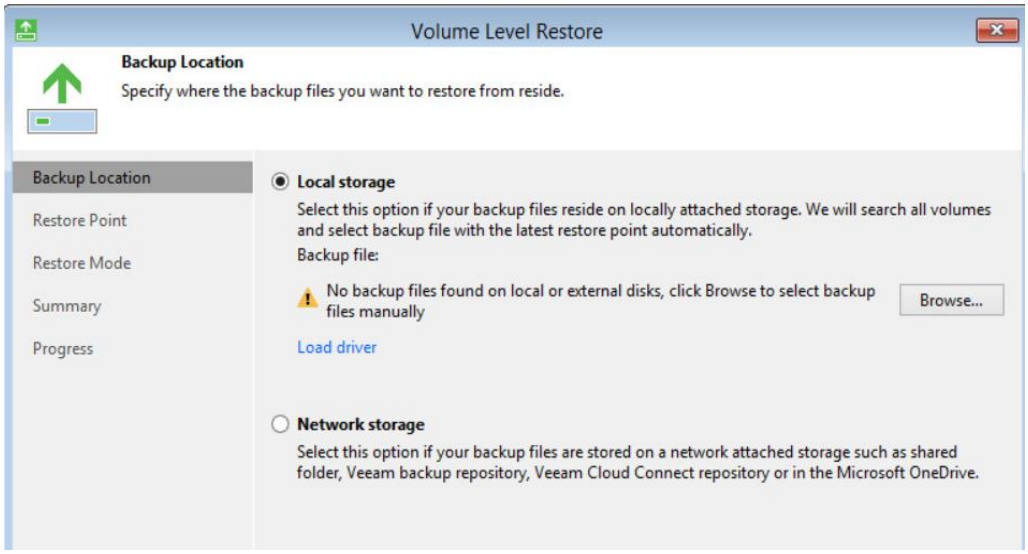


5. To perform a backup of **File-Level** Type
    a. Repeat Steps listed above in Step 4, except for one change. Select the Backup Mode as **File-Level (Slower)**.
    b. Select the Directories to be backed up. Click **Next** to complete the remaining steps.

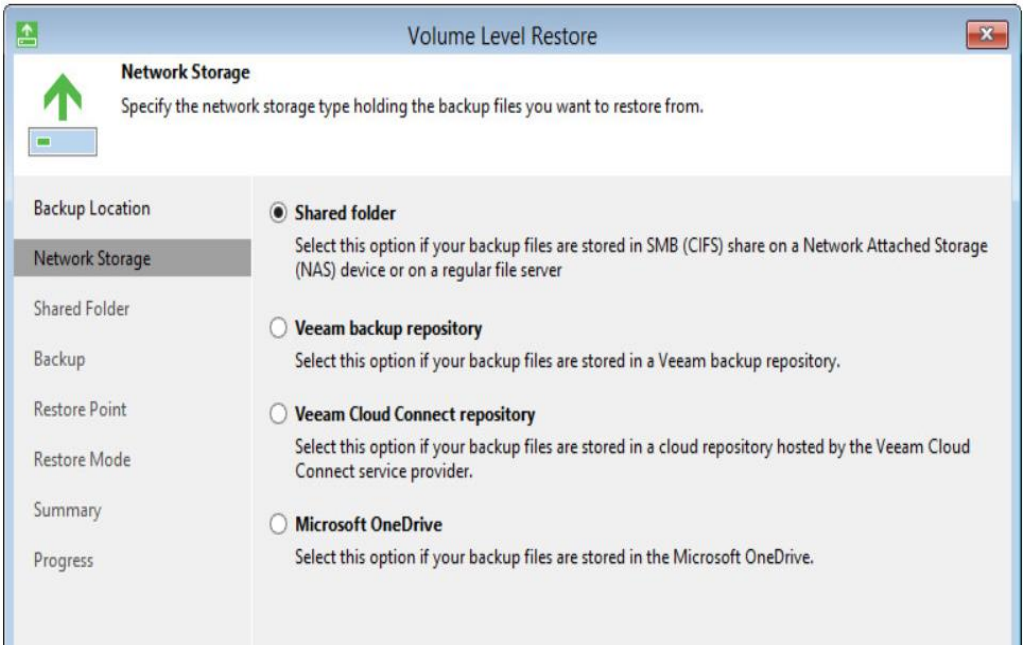
4.6.5.4 Performing Recovery

1. Follow the steps below to Restore Individual files
    a. Double click on the Veeam Agent in Windows System tray of the client > **Restore** > **Individual Files**.
    b. Select **Network Storage** as the location under **Backup Location** page. Hit **Next**.
    c. Select **Shared folder** under **Remote Storage**. Click **Next**.
    d. Specify the UNC path and access-credentials of the shared folder under **Shared folder**. For instance, \\10.100.0.10\backups\workstation in our case.
    e. Select a Restore point from which you want to recover data at the Restore Point step. Click **Next** to initiate the Restore process.
    f. Review the steps at the Summary page

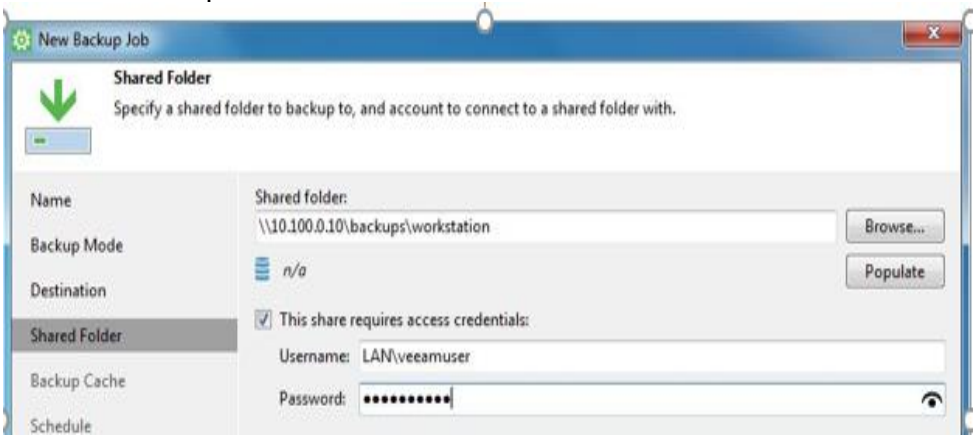
2. Follow the steps below to Recover Volumes or an **Entire Computer** image,
    a. Boot the system using the Recovery media created earlier. Click on **Bare Metal Recovery**
    b. Select **Local Storage** if restoring backups from an External USB Drive or **Network Storage** if restoring from a network share as in our case.



c. Configure Network Settings. Choose either DHCP or Static IP and hit Continue
d. Select **Share folder** at the **Network Storage** Step. Hit **Next**

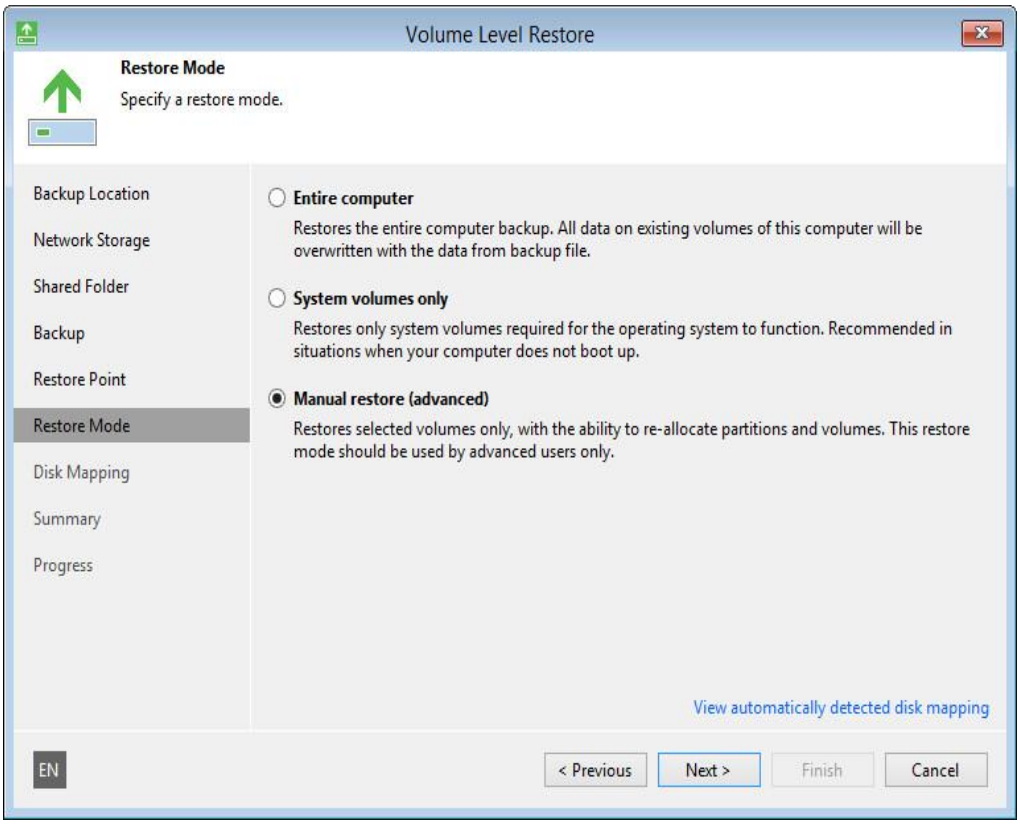


e. Enter the UNC- path and access-credentials of Share folder to restore from.



f. Select a **Backup** from the list of backups the wizard displays and hit Next.
g. Select a **Restore point** under **Restore Points** from which you want to recover data.

h. Select a Restore Mode at the **Restore Mode** step. If the disk type and layout on the system has not changed select "Entire Computer". There is a Manual restore available for advanced users.



i. Map restored drives as per your system layout under **Disk Mapping step**[68].
j. Review the summary at the Summary page. Hit Restore to start the restore process.

[68] https://helpcenter.veeam.com/docs/agentforwindows/userguide/baremetal_disk_mapping.html?ver=30

4.6.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Veeam Backup tool while the manufacturing system was operational:

Experiment PL009.2- Veeam full backup
Experiment PL010.1- Veeam incremental backup

A small performance impact to the manufacturing process was observed in, however, a more noticeable impact was observed in the network traffic. For example, the round trip time from the Controller to the OPC was increased significantly during the backup. The path delay from the OPC to HMI was also increased significantly during the backup. The amount of backup traffic could take up a large portion of the available bandwidth.

Also, there is storage consideration, example of backup size in the PCS system: HMI: 96 GB, OPC: 29 GB, Controller: 31 GB, Historian: 194 GB

Network usage should be taken into consideration on when to perform a full backup, a low network utilization time is likely to reduce the impact to the system. One important feature of the Veeam backup is its ability to throttle to adapt to the network utilization in order to avoid taking up all the available bandwidth for the backup traffic.

Incremental backup should be considered for periodic backup instead of full image backup.

During the full backup, the network traffic increased dramatically. In one case, the backup of the HMI and Controller hosts represented 99.6 % of the total traffic verse 0.4 % of the normal traffic.

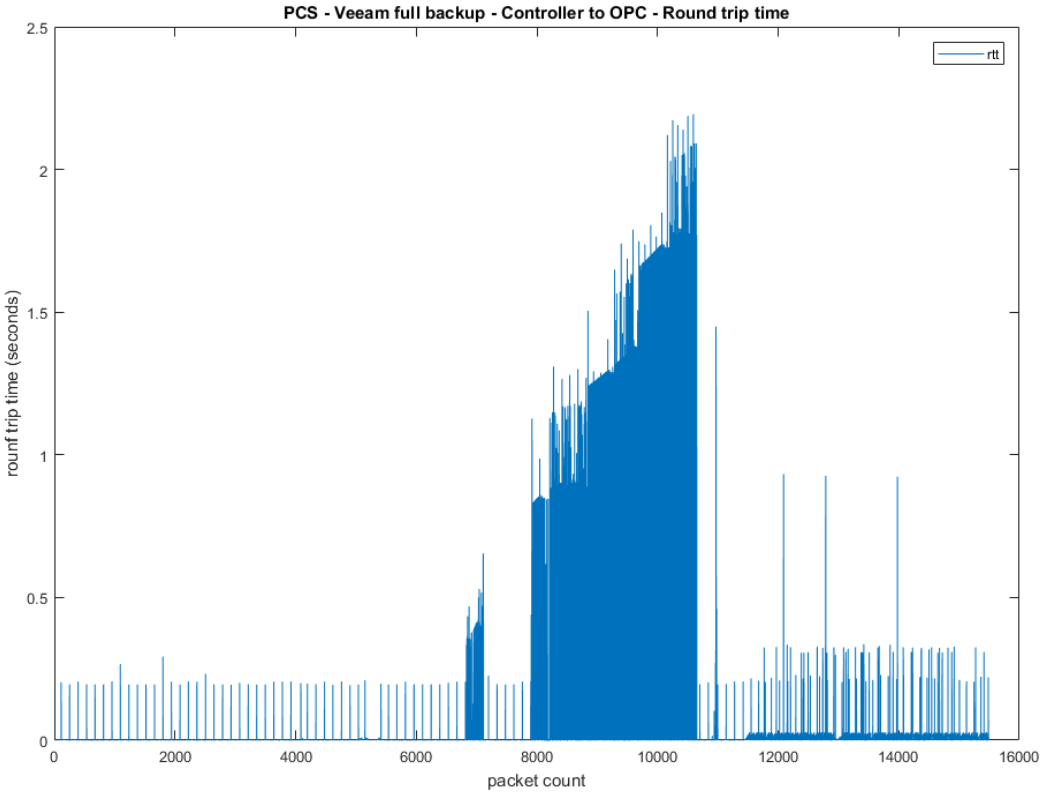


Figure 4-7 Plot of packet round trip time from Controller to OPC during Veeam full backup

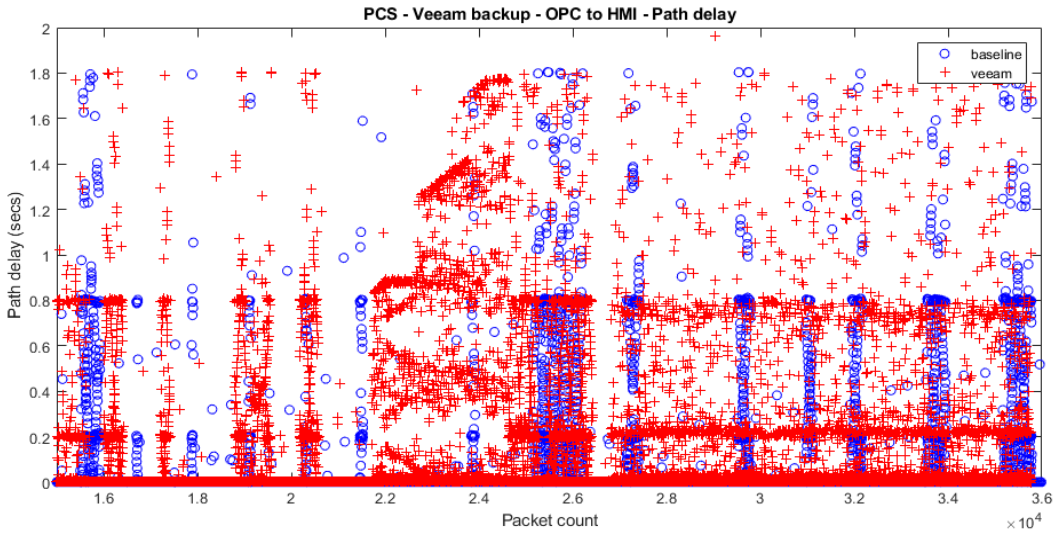


Figure 4-8 Plot of the path delay from OPC to HMI during Veeam full backup

Incremental backup should be considered. The amount of network resources consumed was much lower compare with a full backup. The round trip time from Controller to OPC during an incremental backup was increased only for a short amount of time.

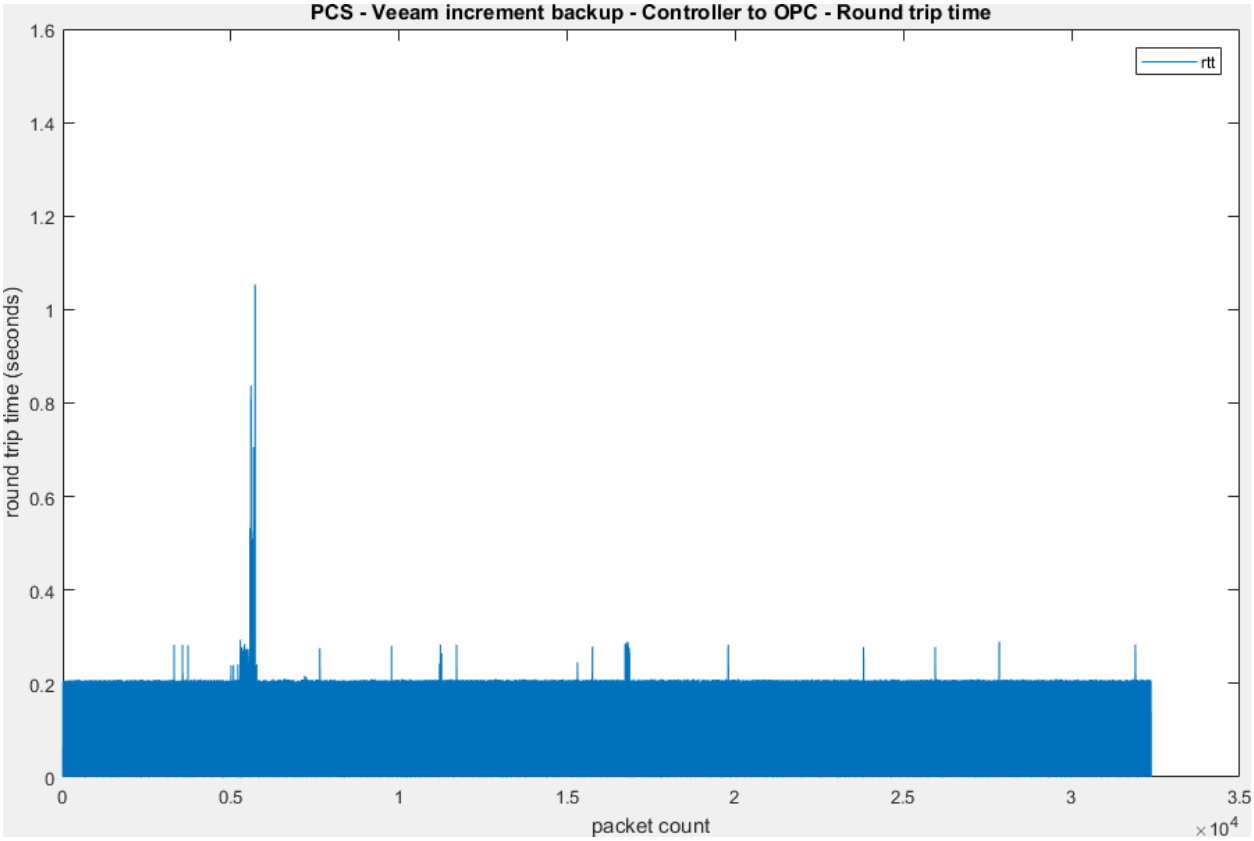


Figure 4-9 Plot of the packet round trip time from Controller to OPC during Veeam incremental backup

There was a small performance impact to the manufacturing process observed during the full backup. The product flow was slightly lower, and the reactor pressure overshot the normal levels in the experiment.

It is hypothesized that the impacts were caused by increased network latency and traffic which caused a delay of the sensor and actuator information exchange between the Controller and the simulated plant. Therefore, degraded performance of the control loop caused a slight impact to the performance of the system. The ability of the Veeam backup to throttle the rate of backup according to the network condition helped reduce the impact to the network traffic and latency during the full backup.

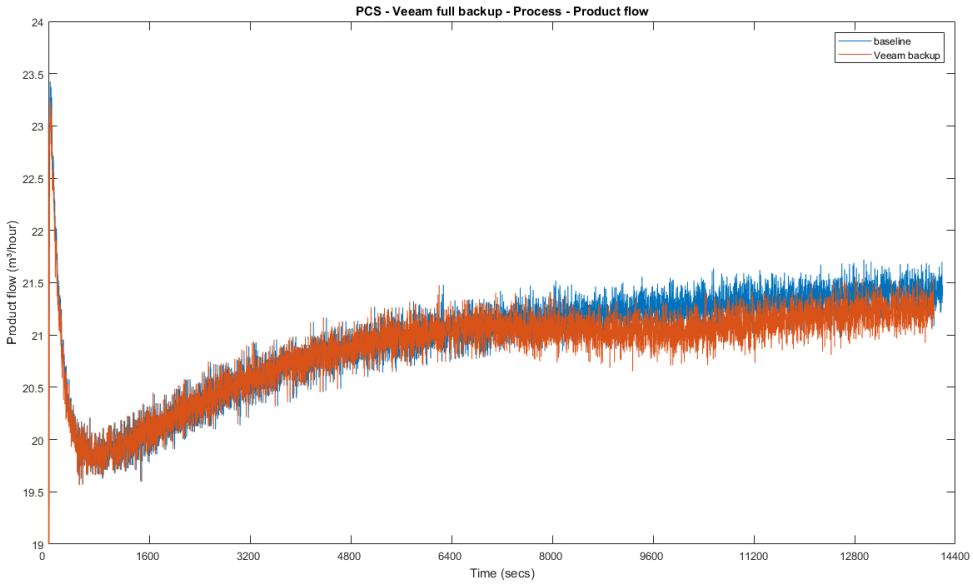


Figure 4-10 Plot of the production flow of the manufacturing process during Veeam full backup

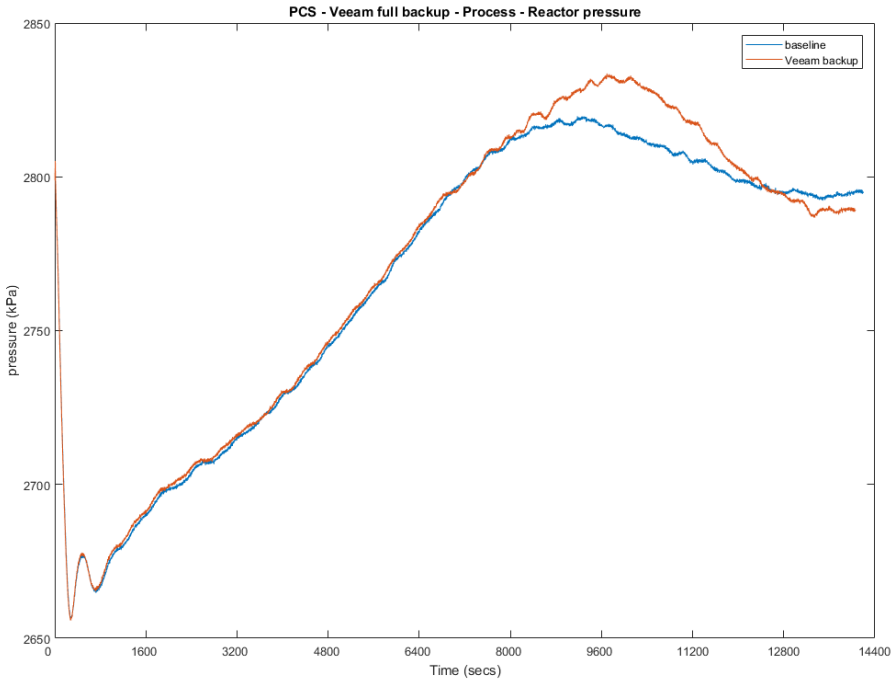


Figure 4-11 Plot of the reactor pressure of the manufacturing process during Veeam full backup

4.6.7 Links to Entire Performance Measurement Data Set

- **Veeam full backup KPI data**
- **Veeam full backup measurement data**
- **Veeam incremental backup KPI data**
- **Veeam incremental backup measurement data**

4.7 Security Onion

4.7.1 Technical Solution Overview

Security Onion is a free and open source Linux distribution for intrusion detection, enterprise cybersecurity monitoring, and log management. It includes Elasticsearch, Logstash, Kibana, Snort, Suricata, Bro, OSSEC, Sguil, Squert, NetworkMiner, and other cybersecurity tools.[69]

Security Onion combines three core functions:

- full packet capture
- network-based and host-based intrusion detection systems (NIDS and HIDS, respectively)
- and powerful analysis tools

Points to consider:

- Open source software, available as an ISO distribution to deploy in any type of environment (physical or virtual).
- Collection of different open-source tools such as SNORT, BRO, OSSEC SGQUIL, KIBANA, ELSA etc. integrated into one product which otherwise would require a lot of manual work to integrate.
- Support for standalone instance and distributed deployment for large organizations.
- Provides a front-end to Snort and BRO IDS which are natively command line-based.
- Fully customizable rule-set. Has inbuilt detection rules to detect a variety of cyber-attacks and anomalies for both IT and OT environments.
- Learning curve associated. Familiarity with SNORT and BRO IDS rule-set.
- Hardware resource intensive.
- No reporting capabilities out of the box.

4.7.2 Technical Capabilities Provided by Solution

Security Onion provides components of the following Technical Capabilities described in Section 6 of Volume 1:

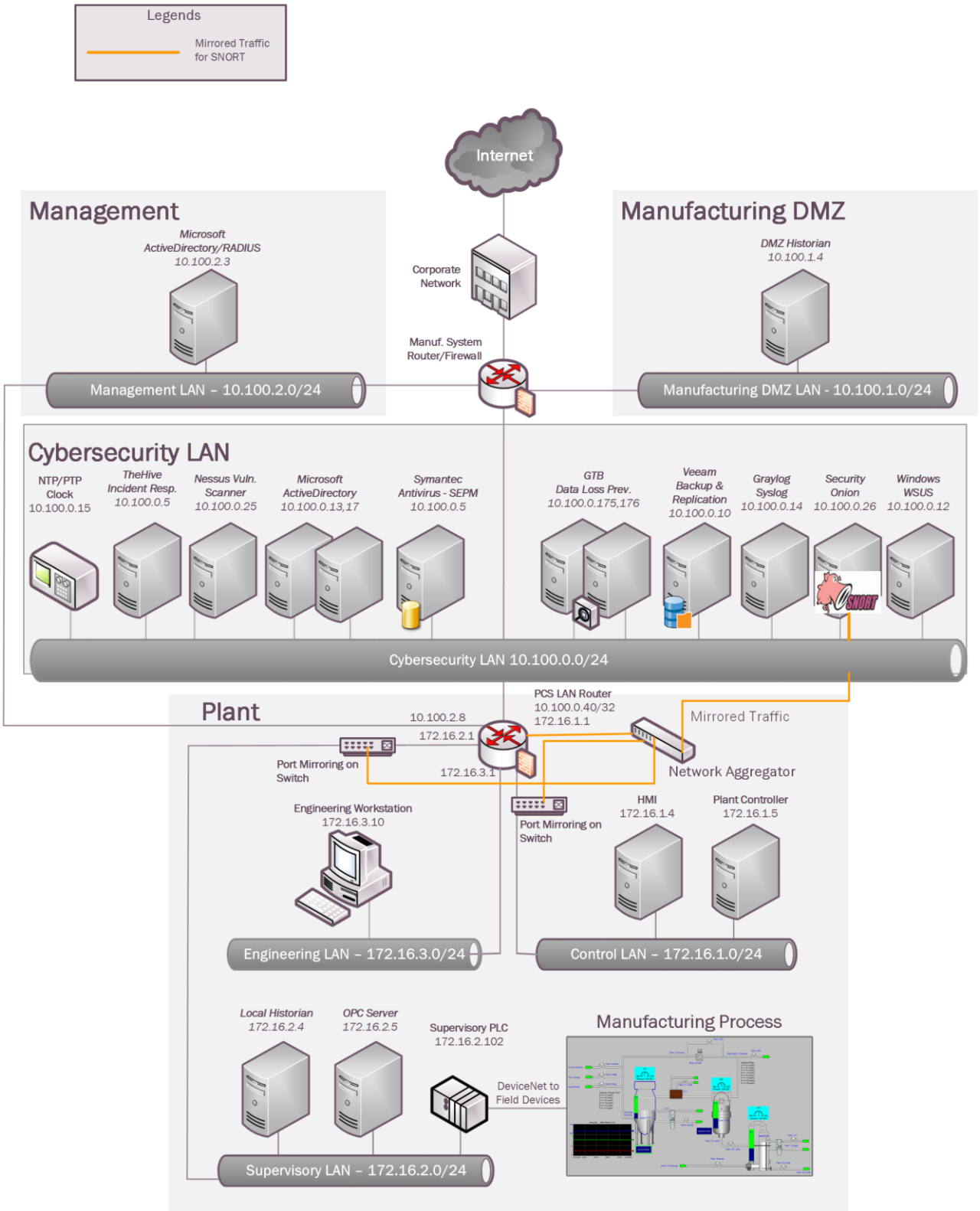
- Network Boundary Protection
- Network Monitoring
- Event Logging
- Forensics

4.7.3 Subcategories Addressed by Implementing Solution

PR.AC-5, PR.DS-5, PR.MA-2, PR.PT-1, PR.PT-4, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-6, DE.CM-7, DE.DP-3, RS.AN-3

[69] https://securityonion.net/

4.7.4 Architecture Map of Where Solution was Implemented



4.7.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware Details
Security Onion	16.04.5.2	Hyper-V Virtual Machine • Processors: 4 virtual cores • Memory: 20 GB • Disk space: 500 GB • Network: 2 interfaces • Operating System: Ubuntu 16.04

4.7.5.1 Security Onion Environment Setup

1. A virtual machine running customized version of Ubuntu Linux 16.04 as provided by the Vendor with hardware specifications as described in the table above.
2. Configured two network connections to the virtual machines as follows

   ```
   Interface: eth0
   ```
   Mode: Primary interface for management .

   ```
   Interface: eth1
   ```
   Mode: Monitoring port with the connection originating from a Network Aggregator device that was configured to receive Mirrored traffic from all the three network devices of the plant .

3. The guest OS IP information was set as follows:

   ```
   Interface: eth0
   IP address: 10.100.0.26
   Gateway: 10.100.0.1
   Subnet Mask: 255.255.255.0
   DNS:10.100.0.17
   ```

4.7.5.2 Setup Instructions

1. Download the ISO image of Security Onion[70] and deploy it on your Hyper-visor of choice.
2. Review the hardware requirements[71] prior to proceeding with the next steps.

[70] https://securityonion.net
[71] https://securityonion.readthedocs.io/en/latest/

3. Setup the two network connections for the virtual machine before powering it ON as follows.
   - **(eth0)** for management IP address
   - **(eth1**) for the monitoring interface. This connection would be either from a SPAN port or a Network TAP which is receiving mirrored traffic from all network devices.
4. Power-On the VM, Complete the default OS setup. Perform a reboot.
5. Ensure to set the OS time-zone to UTC as Security Onion uses UTC by default. Changing time-zone can cause other issues.
6. Login to the console locally and click on the Setup icon on the Desktop to configure the network interfaces. Reboot when done.6. Click on the **Setup** icon again to complete next phase of the setup.
7. Click **YES, Continue!** and then select **Evaluation Mode** in the next screen for standalone deployments.
8. Follow the on-screen options and complete the wizard. A system reboot would again be required.
9. Configure appropriate firewall rules for remote connectivity,
   a. Run `sudo so-allow`
   b. Select **a – analyst** option
   c. Enter the IP address or ip-range of client-pc where you intend to access security onion interface from.

   Instructions to setup a firewall[72] are available from Security Onion.

10. Run the command `sudo nsm_sensor_ps-status` to check the status of each component
11. Access the Security Onion application either via the SQUERT Web interface[73] or via Kibana.[74]

4.7.5.3 Configuring Snort Updates

1. Register for an account on https://snort.org to be eligible for downloading the Registered Rule set. Upon registration, note down the **oink** code tied to your account.
2. Copy-paste the OINK code in the **rule_url** parameter in */etc./nsm/pulledpork/pulledpork.conf* file of the server and save the changes.

   ```
   rule_url=https://www.snort.org/reg-rules/|snortrules-
   snapshot.tar.gz|<oink-code>
   ```

3. For systems with Internet Access,
4. Uncomment & Set `LOCAL_NIDS_RULE_TUNING=no` in the */etc./nsm/securityonion.conf*

[72] https://github.com/Security-Onion-Solutions/security-onion/wiki/Firewall
[73] https://IP address-of-security-onion/
[74] https://ip-address-of-security-onion/app/kibana

5. Run the `sudo rule-update` command to update the rule set. This will download new rules from Snort.org and save them in */etc./nsm/rules/downloaded.rules* file.
6. For Air-Gapped environments (w/o Internet)
   a. Set `LOCAL_NIDS_RULE_TUNING=yes` in the *securityonion.conf* file
   b. Download snort updates manually on a different system which has internet access and transfer these via USB device or network to */tmp* folder on the Security Onion server.
   c. Run `sudo rule-update`

4.7.5.4 Configuring SNORT Rule set

1. Define the network variables such as $HOME_NET, $EXTERNAL_NET etc. as per your environment in the (snort.conf) at */etc./nsm/<hostname-MonitorInterface>/*.
2. Restart Snort services: `sudo nsm_sensor_ps-restart --only-snort`

Below is a snippet of the **snort.conf** in our instance

```
###################################################
# Step #1: Set the network variables.  For more information, see README.variables
###################################################

# Setup the network addresses you are protecting
ipvar HOME_NET [192.168.0.0/16,10.0.0.0/8,172.16.0.0/12]

ipvar NETWORK_DEVICES [172.16.1.3,172.16.3.1,172.16.2.2,192.168.0.239,192.168.0.2,192.168.1.2]
ipvar ICS_DEVICES [172.16.2.102,172.16.4.102,192.168.0.30,192.168.0.60]
ipvar PCS_ICS_DEVICES [172.16.2.100/30]
# Set up the external network addresses. Leave as "any" in most situations
ipvar EXTERNAL_NET !$HOME_NET

# List of DNS servers on your network
ipvar DNS_SERVERS [10.100.0.17]

# List of SMTP servers on your network
ipvar SMTP_SERVERS $HOME_NET
```

3. To define custom rule set:
   a. Define them in */etc./nsm/rules/local.rules* file
   b. Update the Ruleset by running `sudo rule-update`
   c. Run `tail -n 100 /etc./nsm/rules/downloaded.rules` to confirm if the local.rules got merged successfully into the downloaded.rules file
4. Review the */etc./nsm/<interface>/snortu-1.log* if the defined local rules do not appear in the *downloaded.rules* file.

4.7.5.5 Rules Implemented to Monitor our Plant Network

Shown below are some of the rules used in our *local.rules* file to detect common IT and ICS-specific anomalies.

```
# Detect NMAP scan, ICMP attack , TCP-SYN Flood attack
alert UDP any any -> $PCS_ICS_DEVICES any (msg: "Nmap UDP Scan"; sid:10000002; rev:1;)
alert icmp any any -> $HOME_NET any (msg: "NMAP ping sweep Scan"; dsize:0; sid:10000004;
rev:1;)
alert icmp any any -> $HOME_NET any (msg: "Ping Large ICMP Packet"; dsize:>800; classtype:bad-
unknown; sid:10000030; rev:1;)
alert tcp any any -> $HOME_NET [80,22,443] (msg: "TCP SYN flood attack detected"; flow: stateless;
flags:S,12; detection_filter:track by_dst, count 100, seconds 10; classtype: attempted-recon;
sid:10000005; rev:1;)
```

```
# Detect FTP Attempt to Public IP-address & other FTP events
alert tcp $HOME_NET any -> $EXTERNAL_NET 21 (msg: "FTP attempt to Public IP"; sid:10000003;
rev:1;)
alert tcp $HOME_NET any -> any 21 (msg: "FTP upload attempt"; content: "|53 54 4f 52|";
sid:10000020; rev:1;)
alert tcp  any 21 -> $HOME_NET any (msg: "FTP file successfully uploaded"; content: "|54 72 61 6e 73
66 65 72 20 63 6f 6d 70 6c 65 74 65|"; sid:10000027; rev:1;)
alert tcp  any 21 -> $HOME_NET any (msg: "FTP PDF file successfully uploaded"; content: ".pdf";
sid:10000031; rev:1;)

# Detect Credit card number in cleartext
alert tcp any any <> any any (pcre:"/5\d{3}(\s|-)?\d{4}(\s|-)?\d{4}(\s|-)?\d{4}/"; msg: "MasterCard
number detected in clear text"; content:"number"; nocase; sid:10000013; rev:1;)
alert tcp any any <> any any (pcre:"/3\d{3}(\s|-)?\d{6}(\s|-)?\d{5}/"; msg: "American Express number
detected in clear text"; content:"number";nocase; sid:10000014; rev:1;)
alert tcp any any <> any any (pcre:"/4\d{3}(\s|-)?\d{4}(\s|-)?\d{4}(\s|-)?\d{4}/"; msg: "Visa number
detected in clear text"; content:"number";nocase; sid:10000015; rev:1;)

# Telnet activity monitoring
alert tcp $TELNET_SERVERS 23 ->  $HOME_NET any (msg: "Telnet Password in Clear text"; content:
"Password"; sid:10000010;rev:1;)
alert tcp $HOME_NET any -> $TELNET_SERVERS 23 (msg: "TELNET login attempt";
classtype:default-login-attempt; sid:10000007; rev:1;)
alert tcp $HOME_NET any ->  $TELNET_SERVERS 23 (msg: "Telnet Rockwell Automation Default
Password"; content: "|73 77 69 74 63 68|"; sid:10000008;rev:1;)
alert tcp any 23 -> any any (msg: "TELNET login failed"; flow:from_server,established; content:"Login
failed"; fast_pattern:only; nocase; classtype:bad-unknown; sid:10000038; rev:
```

Snort Rules for ICS/ SCADA[75]

```
#ICS-SCADA specific rules [4]
alert tcp $HOME_NET any -> $ICS_DEVICES 44818 (msg: "PROTOCOL-SCADA Rockwell firmware
change attempt"; flow:to_server,established; content:"|6F 00|"; content:"|00 00 00 00|"; within:4; distance:6;
content:"|00 00 00 00|"; within:4; distance:8; pcre:"/(\x20\xa1|\x21\x00\xa1\x00)(\x24[\x01-
\xff]|\x25\x00[\x01-\xff]\x00)/smi"; reference:cve,2012-6437;
reference:url,tools.cisco.com/security/center/viewAlert.x?alertId=27868; classtype:policy-violation;
sid:10000019; rev:1;)
alert tcp $HOME_NET any ->  $ICS_DEVICES $HTTP_PORTS (msg: "ICS-SCADA PLC Web access
attempted "; sid:10000033; rev:1;)
alert tcp any any -> $HOME_NET 22350 (msg: "PROTOCOL-SCADA TwinCAT PLC DOS attempt";
flow:to_server,established; dsize:>2000; content:"|A2 1D CB AA AA 75 48 B4 91 DB F4 06 B0 B0 2D|";
fast_pattern:only; metadata:policy max-detect-ips drop, policy security-ips drop;
reference:url,www.beckhoff.com/english.asp?twincat/overvw.htm; classtype:attempted-dos; sid:41743;
rev:2;)
alert tcp any any -> $ICS_DEVICES 502 (msg: "PROTOCOL-SCADA Modbus user-defined function code
- 65 to 72"; flow:to_server,established; byte_test:1,>,64,7; byte_test:1,<,73,7;
reference:url,www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf; classtype:protocol-
command-decode; sid:15074; rev:5;)
alert tcp any any -> $ICS_DEVICES 502 (msg: "PROTOCOL-SCADA Modbus user-defined function code
- 100 to 110"; flow:to_server,established; byte_test:1,>,99,7; byte_test:1,<,111,7;
reference:url,www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf; classtype:protocol-
command-decode; sid:15075; rev:5;)
alert tcp any any -> $ICS_DEVICES 502 (msg: "PROTOCOL-SCADA Modbus read multiple coils - too
many inputs"; flow:to_server, established; modbus_func:read_coils; byte_test:2,>,2000,10;
reference:url,www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf; classtype:protocol-
command-decode; sid:15077; rev:6;)
alert tcp any any -> $ICS_DEVICES 502 (msg: "PROTOCOL-SCADA Modbus write multiple registers
from external source"; flow:to_server,established; modbus_func:write_multiple_registers;
reference:url,www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf; classtype:protocol-
command-decode; sid:17782; rev:4;)
alert tcp any any -> $ICS_DEVICES 502 (msg: "PROTOCOL-SCADA Modbus write single coil from
external source"; flow:to_server,established; modbus_func:write_single_coil;
reference:url,www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf; classtype:protocol-
command-decode; sid:17784; rev:4;)
alert tcp any any -> $ICS_DEVICES 502 (msg: "PROTOCOL-SCADA Modbus write multiple coils from
external source"; flow:to_server,established; modbus_func:write_multiple_coils;
reference:url,www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf; classtype:protocol-
command-decode; sid:17785; rev:4;)
```

[75] Snort Rules for ICS/ SCADA: https://github.com/ITI/ICS-Security-Tools/blob/master/configurations/rules/talos-snort.rules

```
# Accessing switch via Web URL & use of default password
alert tcp  any ->  $NETWORK_DEVICES 80 (msg: " WEBAPP Netgear Default Password";
flow:established,to_server; content:"POST"; nocase; http_method;
uricontent:"/base/cheetah_login.html"; content:"password"; nocase; sid:1000009; rev:1;)
alert tcp $HOME_NET any -> $NETWORK_DEVICES $HTTP_PORTS (msg: "WEBAPP Rockwell
Automation default password login attempt"; flow:to_server,established; content:"Authorization|3A|";
nocase; http_header; content:"YWRtaW5pc3RyYXRvcjptbDE0MDA="; fast_pattern:only; http_header;
metadata:service http; classtype:default-login-attempt; sid:10000011; rev:1;)

# SSH Activity monitoring
alert tcp any any -> $EXTERNAL_NET 22 (msg: "SSH Attempt to Public Host"; sid:10000018; rev:1;)
alert tcp any any -> $HOME_NET 22 (msg: "Potential SSH Brute Force Attack"; flow:to_server,
established; flags:S+; detection_filter:track by_src, count 30 , seconds 10; classtype:attempted-dos;
priority:1; sid:10000006; rev:1;)

# DNS traffic to social media websites
alert udp $HOME_NET any -> $DNS_SERVERS 53 (msg: "DNS Request to Twitter.com Detected";
content: "|6e 69 73 74|"; sid:10000016; rev:1;)
alert udp $HOME_NET any -> $DNS_SERVERS 53 (msg: "DNS Request to Facebook.com Detected";
content: "|66 61 63 65 62 6f 6f 6b|"; sid:10000017; rev:1;)

# File upload activity to a public web server
alert tcp $HOME_NET any -> $EXTERNAL_NET $HTTP_PORTS (msg: "WEB-PHP file upload
attempt"; flow:to_server, established; uricontent:"/upload.php"; nocase; content:"filename=";
reference:bugtraq,3361; reference:cve,2001-1032; classtype:attempted-admin; sid:10000029; rev:1;)
alert tcp $Robotics_devices any -> $EXTERNAL_NET $HTTP_PORTS (msg: "Web Access to Public
IP attempted"; sid:10000039; rev:1;)
```

4.7.5.6 Tuning Security Onion:

1. Set the **DAYSTOKEEP** parameter in the */etc./nsm/securityonion.conf* file to change the database retention period. The default retention period for Sguil database is 30 days
2. To use any of the commented-out rules from *downloaded.rules* file, note down the Generator ID (GID) and Signature ID (SID) value defined in the rule that's commented out and list them in `/etc./nsm/pulledpork/enablesid.conf` file. Avoid directly uncommenting these in the downloaded.rules file.
3. To silence any false alerts, note down the Generator ID (GID) and Signature ID (SID) value of the rule that is generating the alert and define them in the */etc./nsm/pulledpork/disablesid.conf* file. Shown on the next page is a snippet from our **disablesid.conf** file showing the SIDs we have disabled.

```
# example disablesid.conf V3.1

# Example of modifying state for individual rules
# 1:1034,1:9837,1:1270,1:3390,1:710,1:1249,3:13010
3:19187
119:19 # http_inspect: LONG HEADER
123:8 # frag3: Fragmentation overlap
128:4 # ssh: Protocol mismatch
129:4 # stream5: TCP Timestamp is outside of PAWS window
129:5 # stream5: Bad segment, overlap adjusted size less than/equal 0
129:7 # stream5: Limit on number of overlapping TCP packets reached
129:12 # stream5: TCP Small Segment Threshold Exceeded
```

4. Follow the instructions on the wiki for managing the size of pcap files to maintain the storage space on server.

4.7.5.7 BRO IDS Setup

Zeek (formerly known as BRO) is a powerful IDS that comes preinstalled in Security Onion server alongside Snort. It is beyond the scope of this document to explain detailed working of BRO. At a high level,

1. Place any custom scripts for BRO in */opt/bro/share/bro/policy/* directory. Refer to the security onion wiki[76] for additional reference on BRO.
2. Enable Windows SMB File share monitoring as follows,
    a. Add the below line at the end of */opt/bro/share/bro/site/local.bro* file

    ```
    @load policy/protocols/smb
    ```

    b. Restart BRO: `sudo nsm_sensor_ps-restart --only-bro`

4.7.5.8 OSSEC Setup

Ossec is a Host Intrusion Detection System (HIDS) supported on both Windows & Linux platforms. The OSSEC server (now replaced with Wazuh) comes pre-installed with Security Onion. It is beyond the scope of this document to explain detailed working of the OSSEC product. The Ossec official website and other documentation links under References can be a useful source.

1. Download the Ossec agent installer[77] specific to your Operating System.

[76] https://securityonion.readthedocs.io/en/latest/
[77] http://www.ossec.net/

2. Copy over the agent to the client system and run the setup process using the instructions mentioned on the Ossec website. During the install, mention the IP address of Security Onion server as the IP address of Ossec server.
3. Run the command `so-allow` to manage firewall settings on the Security Onion server to receive data from Ossec clients.[78]
4. Add any custom OSSEC rules for monitoring to the **local_rules.xml** file under **/var/ossec/rules** directory. If a decoder is required to parse custom logs, it should be defined under in **local_decoder.xml** file under **/var/ossec/etc.** directory.
5. View the Ossec alerts either from Kibana Interface or Squert web interface
6. To monitor USB drive detection using OSSEC:
   a. Add the following lines[79] to the local *Ossec.conf* file on the Windows endpoint

```
<agent_config os="Windows">
 <localfile>
  <log_format>full_command</log_format>
       <command>reg QUERY
       HKLM\SYSTEM\CurrentControlSet\Enum\USBSTOR</command>
  <alias>usb-check</alias>
 </localfile>
</agent_config>
```

   b. Add the following lines to the */var/ossec/rules /local_rules.xml* file on the Security Onion server to generate an alert

```
<rule id="140125" level="7">
 <if_sid>530</if_sid>
 <match>ossec: output: 'usb-check':</match>
 <check_diff />
 <description>New USB device connected</description>
</rule>
```

7. To monitor for Unauthorized assets on the network:
   a. Install the arpwatch package on the Security Onion server
   b. Run `arpwatch -i <interface>` command to start the service

      For instance: `arpwatch -i eth1` where eth1 is monitoring port.

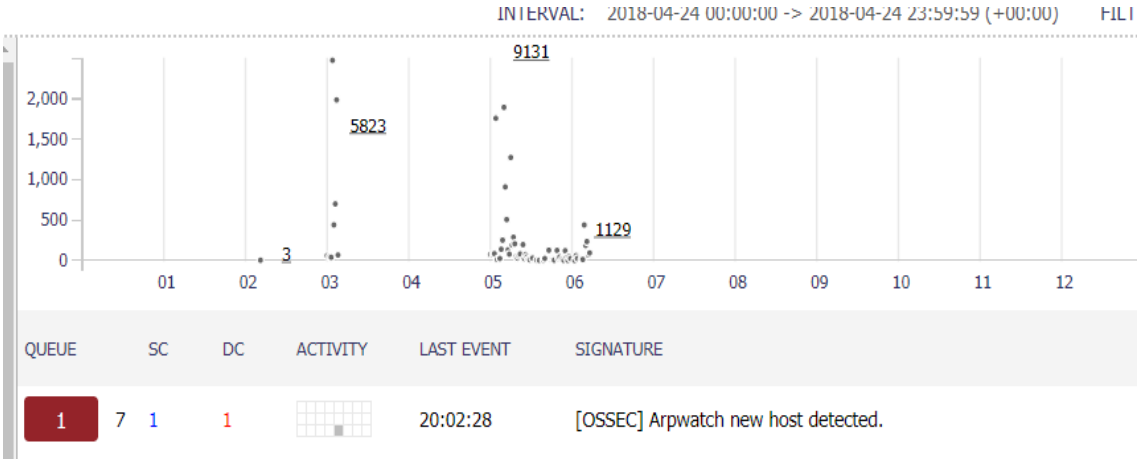
[78] https://github.com/Security-Onion-Solutions/security-onion/wiki/Firewall
[79] https://www.ossec.net/docs/manual/monitoring/process-monitoring.html

c. Add a new rule to the *local_rules.xml* file as shown below. This references this inbuilt decoder at **/var/ossec/etc./arpwatch_decoder.xml** and alerts when a new device is plugged into our network

```
<rule id="110003" level="7">
  <if_sid>7200</if_sid>
  <match>new|logon</match>
  <description>Arpwatch new host detected. </description>
  <group>new_host,</group>
 </rule>
```

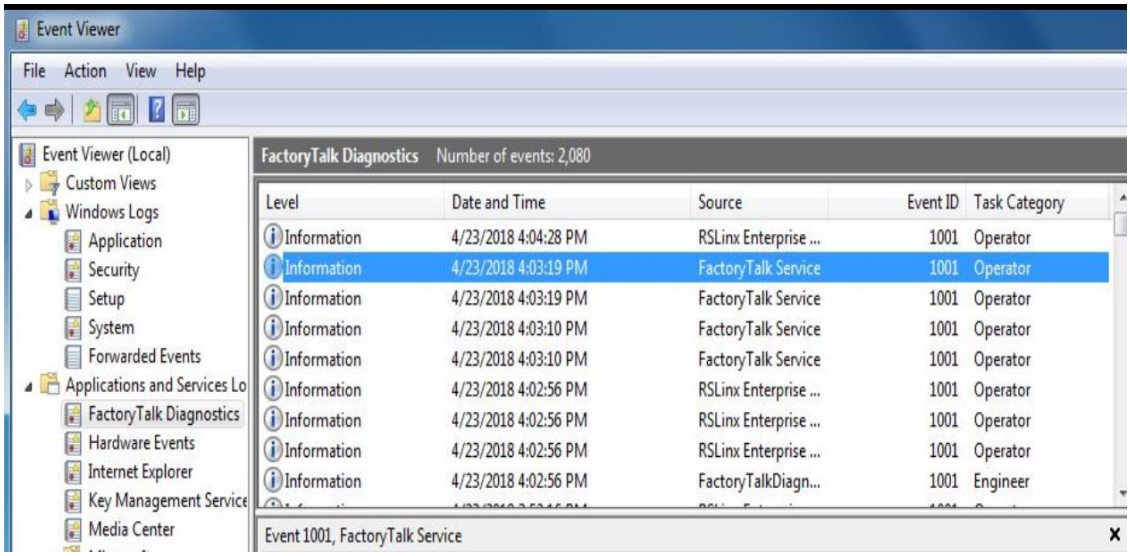
d. Restart OSSEC server after adding any local /rules with the command
`sudo service ossec-hids-server restart`

The image below shows a sample alert in Squert Web Interface, when a new system was physically connected to the network:

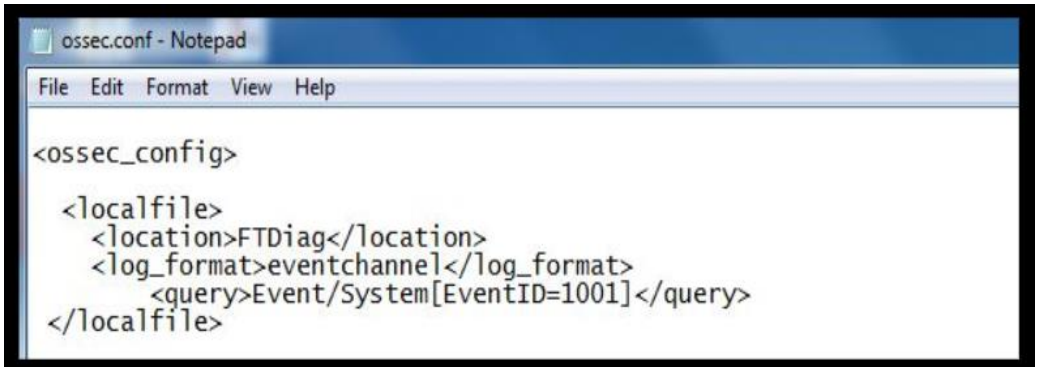


Note: This package relies on the local **ARP cache** of the system to detect new devices.

8. To monitor for Specific events from Windows hosts using OSSEC
   - Note down the EventID to alert on from the Event Viewer. For instance, assume you need to monitor EventID **1001** belonging to Factory Talk Service, which is the Event generated for any login failures from Rockwell Factory Talk software.



- Edit the local *ossec.conf* of the client to include this EventID in question under the <location> attribute of the Event category. For instance:



- Define a corresponding rule in the *local_rules.xml* file to generate an alert. Ensure to set **level >=7** for Ossec to generate an alert. For instance:

```
<group name="syslog,">
<rule id="110001" level="0">
  <if_sid>18104</if_sid>
   <match>FactoryTalkDiagnostics</match>
  <description>FactoryTalk Audit Event</description>
 </rule>
<rule id="110002" level="7">
  <if_sid>110001</if_sid>
  <match>failure</match>
  <description>FactoryTalk Administration Console login failure</description>
 </rule>
```

Lessons Learned:

The full packet capture feature in Security Onion can fill up the hard disk space quickly depending on the amount of network traffic in your environment. Ensure to plan and allocate substantial amount of storage for the server along with configuring the necessary data retention options in securityonion.conf file. Trimming your pcaps can allow you to store them for longer periods of time.[80]

4.7.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the use of Security Onion due to its installation location and how it was used (i.e., the software performed passive analysis of network traffic external to the manufacturing system).

4.7.7 Links to Entire Performance Measurement Data Set

N/A

[80] https://www.netresec.com/?page=Blog&month=2017-12&post=Don%27t-Delete-PCAP-Files---Trim-Them

4.8 Cisco AnyConnect VPN

4.8.1 Technical Solution Overview

The AnyConnect Secure Mobility Client[81] is a modular endpoint software product by Cisco. It provides VPN access through Secure Sockets Layer (SSL) and IPsec IKEv2 and also offers enhanced security through various built-in modules. AnyConnect clients are available across a broad set of platforms, including Windows, macOS, Linux, iOS, Android, Windows Phone/Mobile, BlackBerry, and ChromeOS.

Points to consider:

- Provides additional cybersecurity in the form of Web Security and DNS-Based security.
- OS Platform independent: The VPN clients are supported on Windows, Mac and Linux.
- Administrators can control which networks or resources for endpoints to connect. It provides an IEEE 802.1X supplicant that can be provisioned as part of authentication, authorization, and accounting (AAA) capabilities along with some unique encryption technologies such as MACsec IEEE 802.1AE.
- Cisco Proprietary Product. This replaces the earlier free product called AnyConnect VPN client. You must either have a Cisco Adaptive Security appliance (ASA) Firewall or Cisco Firepower Services Appliance and an active AnyConnect Secure Mobility Client license.

4.8.2 Technical Capabilities Provided by Solution

Cisco AnyConnect VPN provides components of the following Technical Capabilities described in Section 6 of Volume 1:

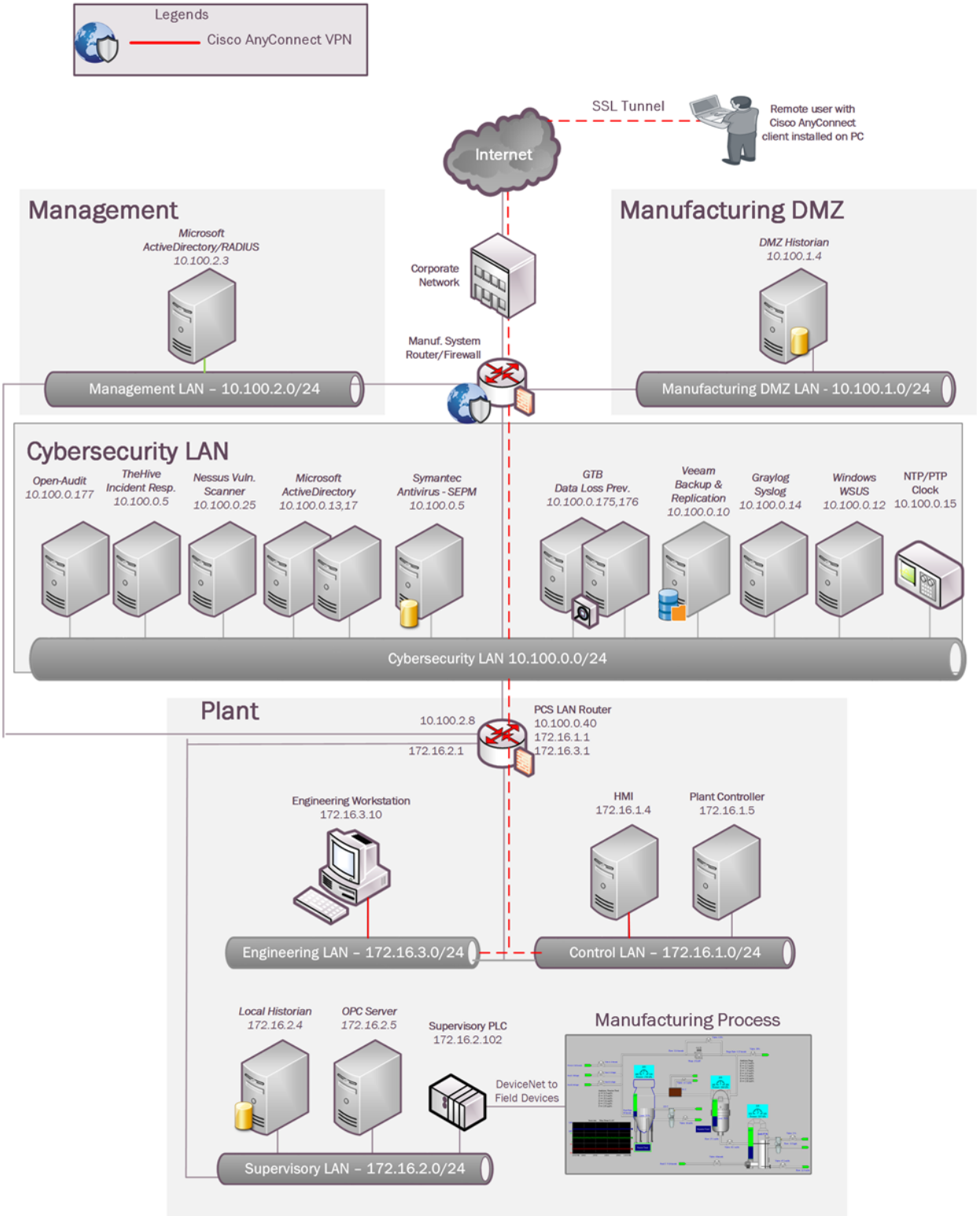
- Secure Remote Access
- Data Replication

4.8.3 Subcategories Addressed by Implementing Solution

PR.AC-5, PR.IP-4, PR.MA-2

[81] https://www.cisco.com/c/dam/en/us/products/collateral/security/anyconnect-secure-mobility-client/at_a_glance_c45-578609.pdf

4.8.4 Architecture Map of Where Solution was Implemented



4.8.5 Installation Instructions and Configurations

Details of the solutions implemented:

Device	Function	OS / Version
Cisco ASA 5512 with Firepower services	Firewall	FTD 6.2.3
AnyConnect VPN	VPN Client software	4.7.01076
Virtual Machine (Mgmt-AD.mgmt.lab)	Active Directory, DNS, NPS (Radius)	Windows 2012 R2

4.8.5.1 Environment Overview

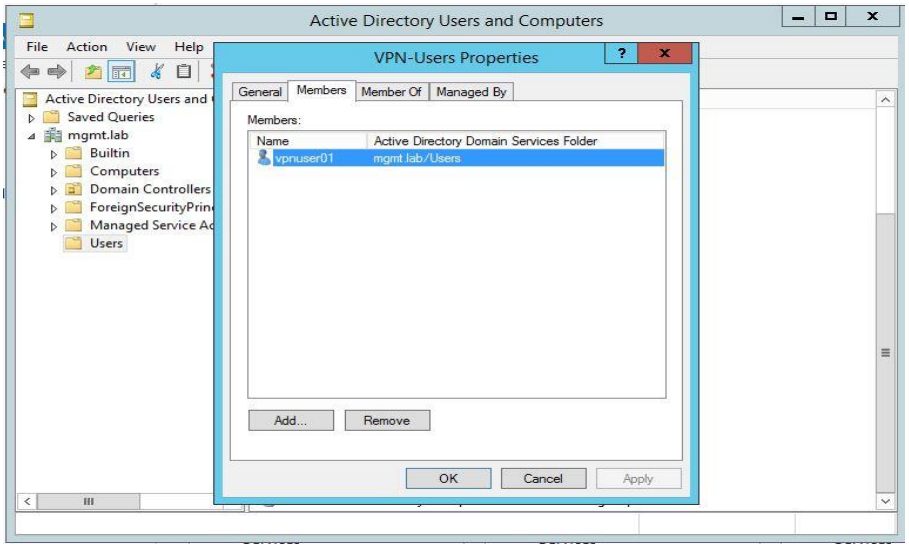
Secure Remote Access was implemented using the Cisco AnyConnect VPN. The AnyConnect VPN was configured on the Cisco ASA firewall in the Cybersecurity LAN network. A Windows server was setup in the Management LAN network of the plant for hosting Active Directory and Radius Authentication services for VPN clients.

4.8.5.2 Setup of a Radius server on Windows

The high-level steps for setting up a Radius server for authenticating Cisco ASA users are:

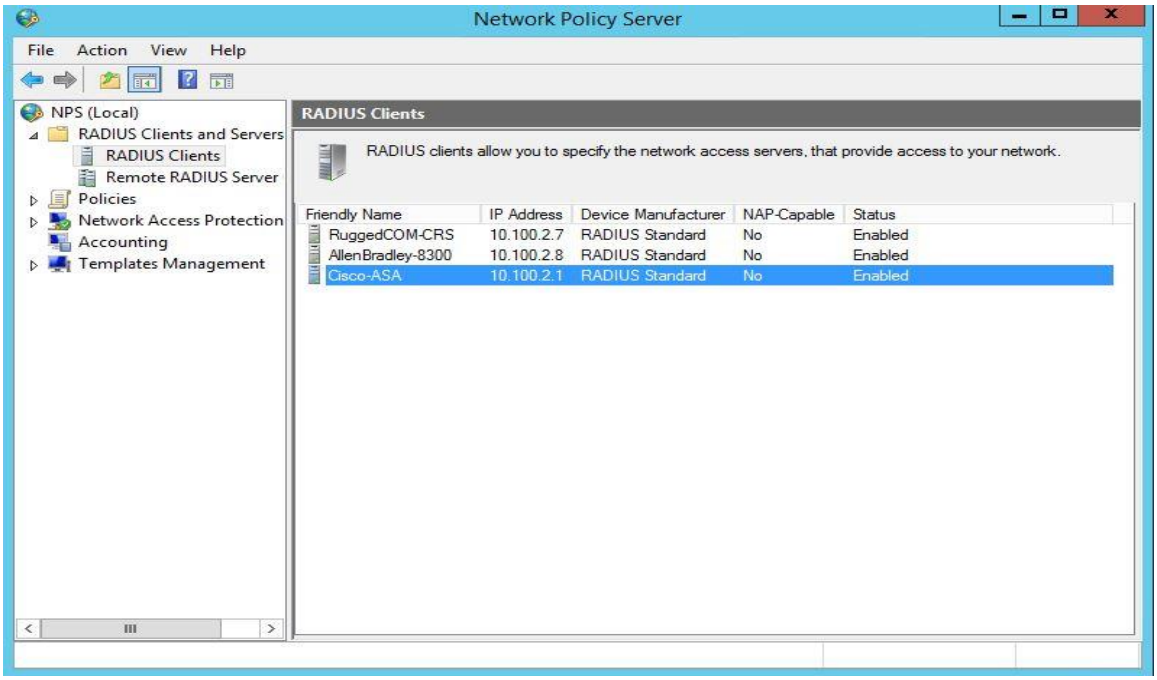
1. Install the following roles on the server either using Server Manager or power shell. Different servers must be used to separate out the Roles and for redundancy.
   - Active Directory Services
   - DNS Server
   - Network Policy Server

2. Create a security group in Active Directory for VPN users and add those users requiring remote access to this group. For instance, a group called **VPN-users** was created in our AD server and a user **vpnuser01** was added to this group.

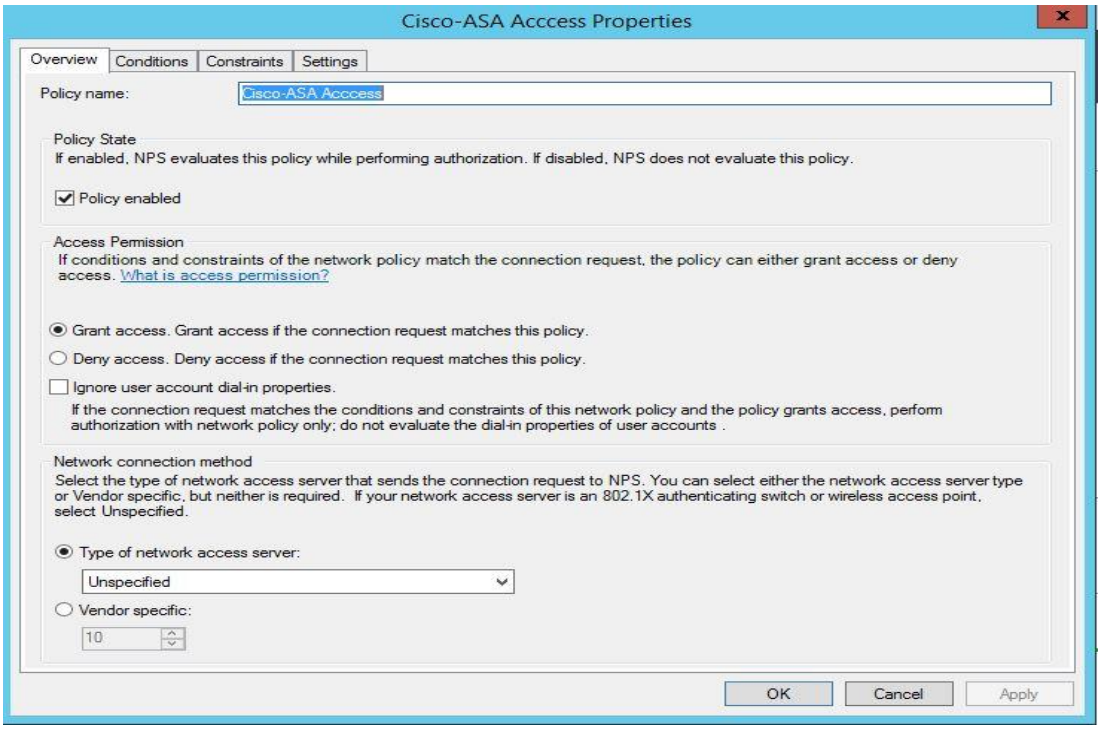


3. Launch the **Network Policy Server** console. Create a new Radius client for your firewall device by clicking on **Radius Clients** > **New**.
4. Enter the IP address of the Interface on the ASA. This is typically the Default Gateway of the subnet where the AD/Radius server is in. Enter a strong passphrase for Shared secret.

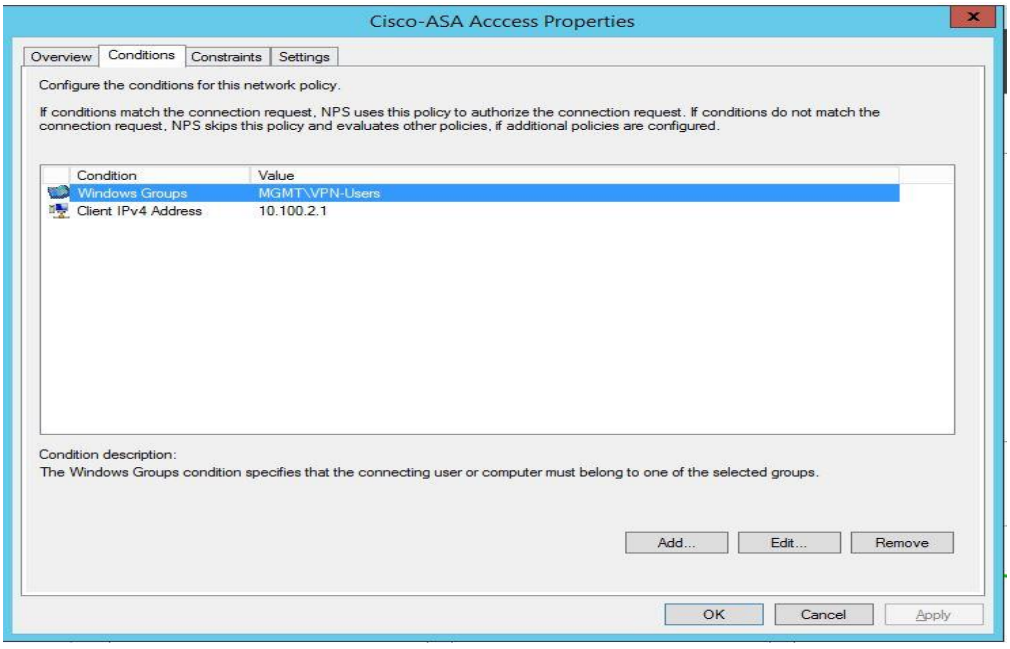
The image below shows a Radius client created for our Cisco-ASA firewall.



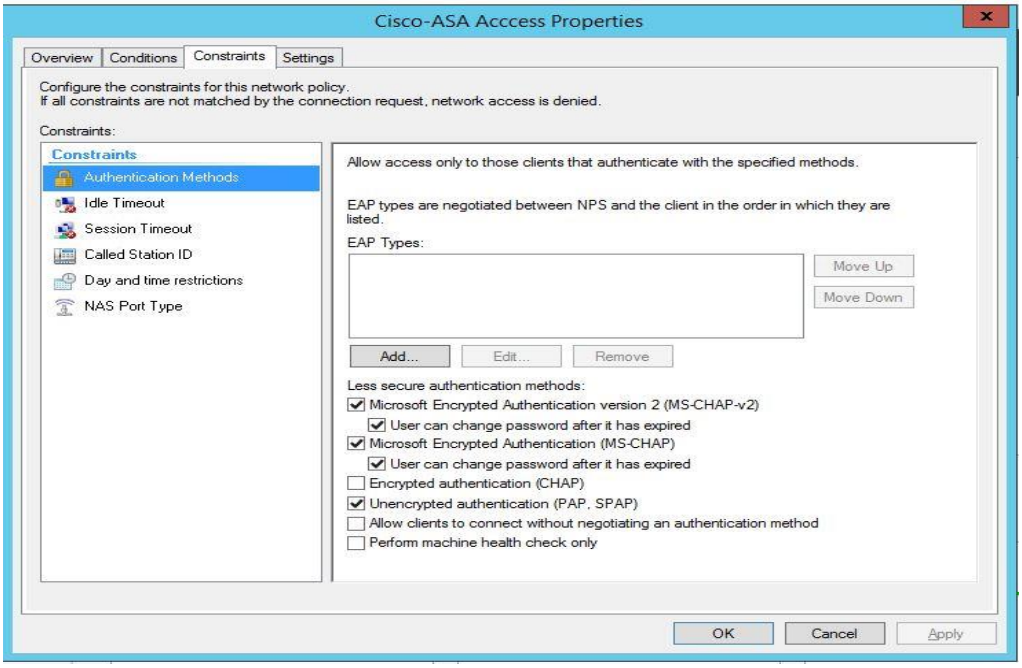
5. Click on **Network Policies** under **Polices**. Create a Network Policy here corresponding to the Radius client setup earlier. The image below shows network policy created for the Cisco-ASA client. Ensure the policy is enabled.



6. Click **ADD** under **Conditions** tab to add the following two conditions at a minimum. Add more conditions as per your requirement.
   - **VPN-Users** security group created earlier.
   - **Client IPv4 Address:** IP address of the Radius client created earlier.

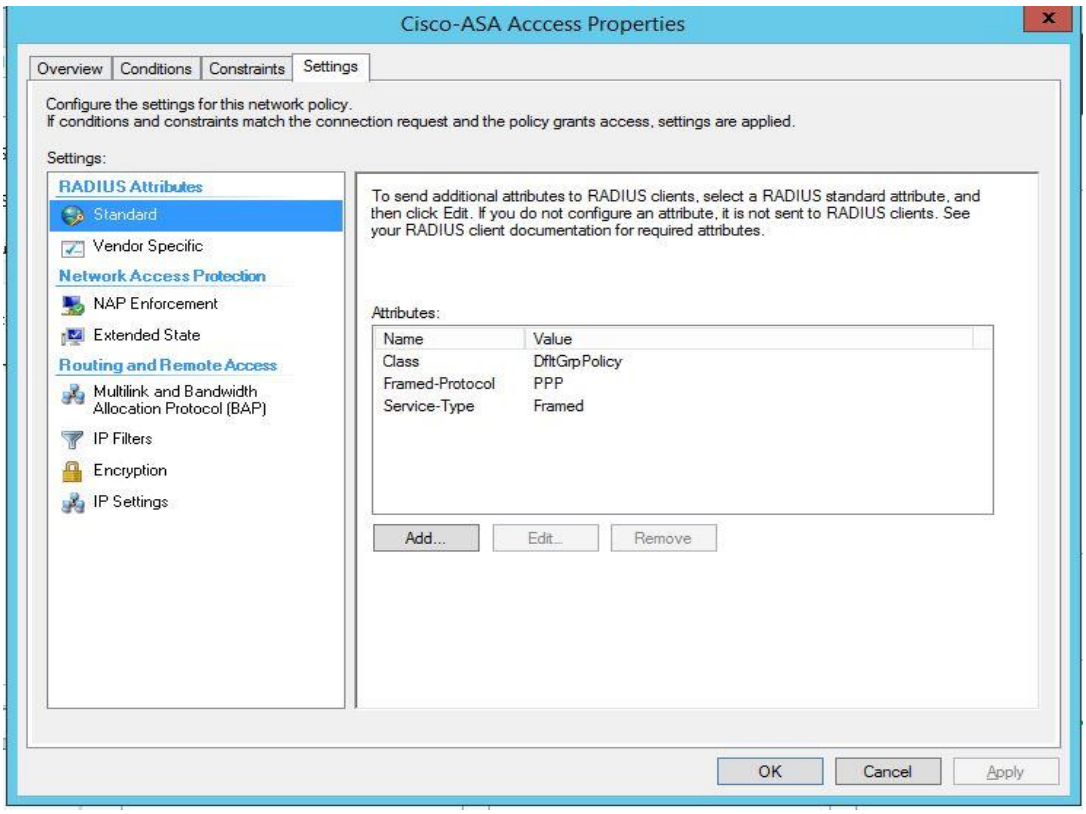


7. Select the **authentication methods** under Constraints as shown below. This is as per Cisco documentation.[82]



[82] https://www.cisco.com/c/en/us/support/docs/security/asa-5500-x-series-next-generation-firewalls/117641-config-asa-00.html

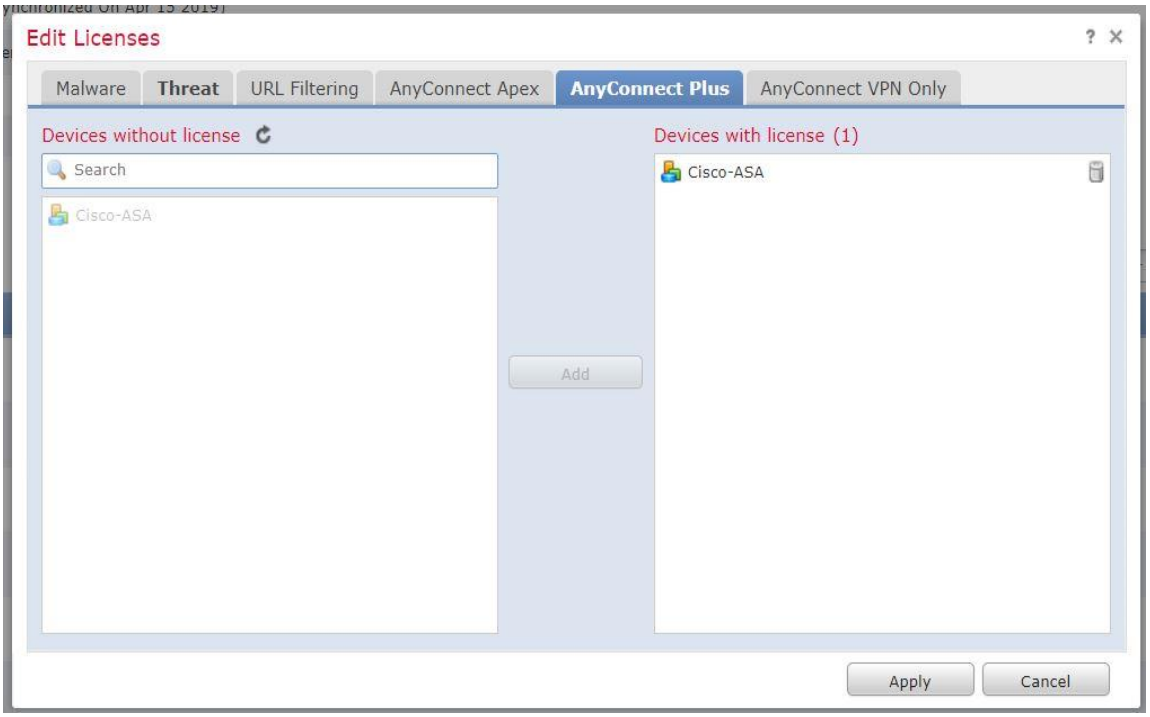
8. Click **Standard** under **Radius Attributes** under **Settings** tab. Set the following attributes
   - Framed Protocol= **PPP**
   - Service-Type=**Framed**
   - Class = <**Name of group policy**>. This policy is configured in the Firewall for VPN



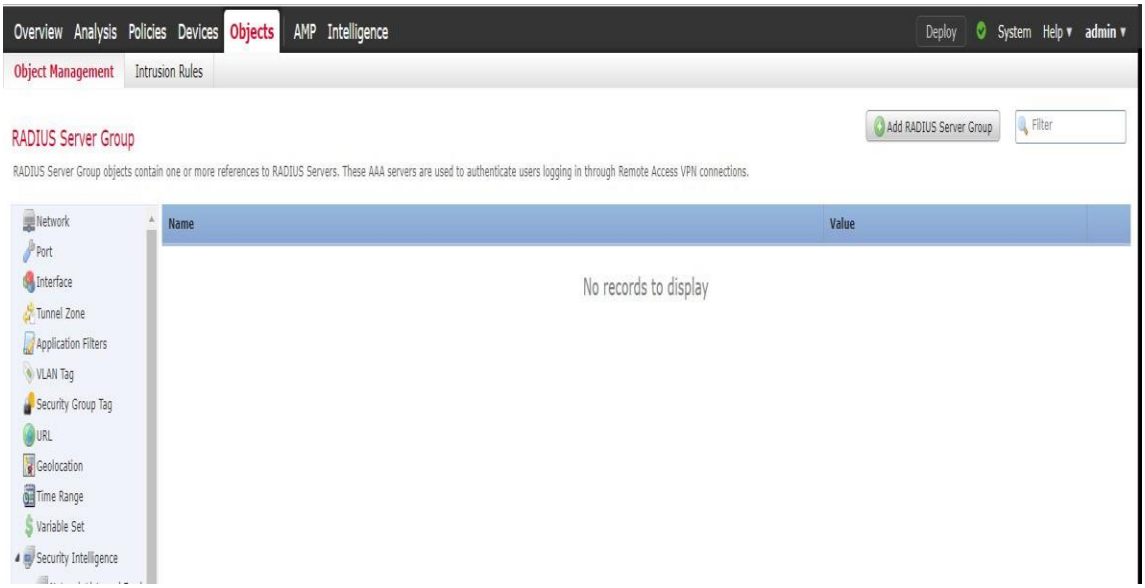
4.8.5.3 AnyConnect VPN Setup on the Cisco-ASA firewall

Below are the high-level steps for configuring Secure Remote Access in the FMC (Firepower Management Console).

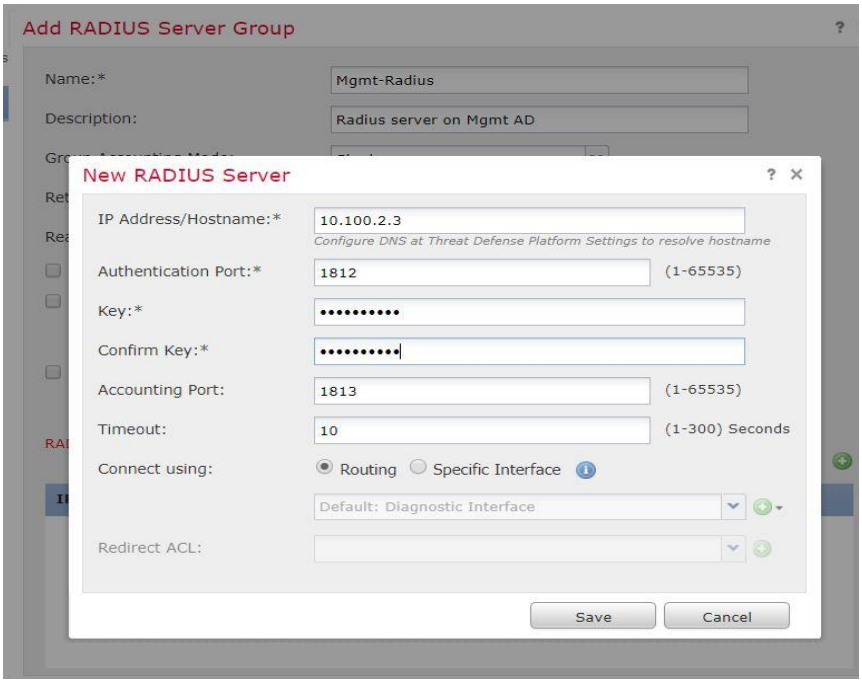
1. Login to the FMC Web interface. Click on **Licenses** > **Smart Licenses** > Verify if either AnyConnect Plus or AnyConnect VPN license has been enabled (if not already).
2. (Optional) Enable a license (assuming an AnyConnect license has been procured and tied to your Cisco smart account) by clicking on **Edit Licenses** > Select the corresponding firewall device from the left side window **Devices without license** and move it to the right side under **Devices with license**. Hit **Apply**.



3. Click on **Objects** menu > **Object Management** > **Radius Server Group** > **Add Radius Server Group** (if not already configured)

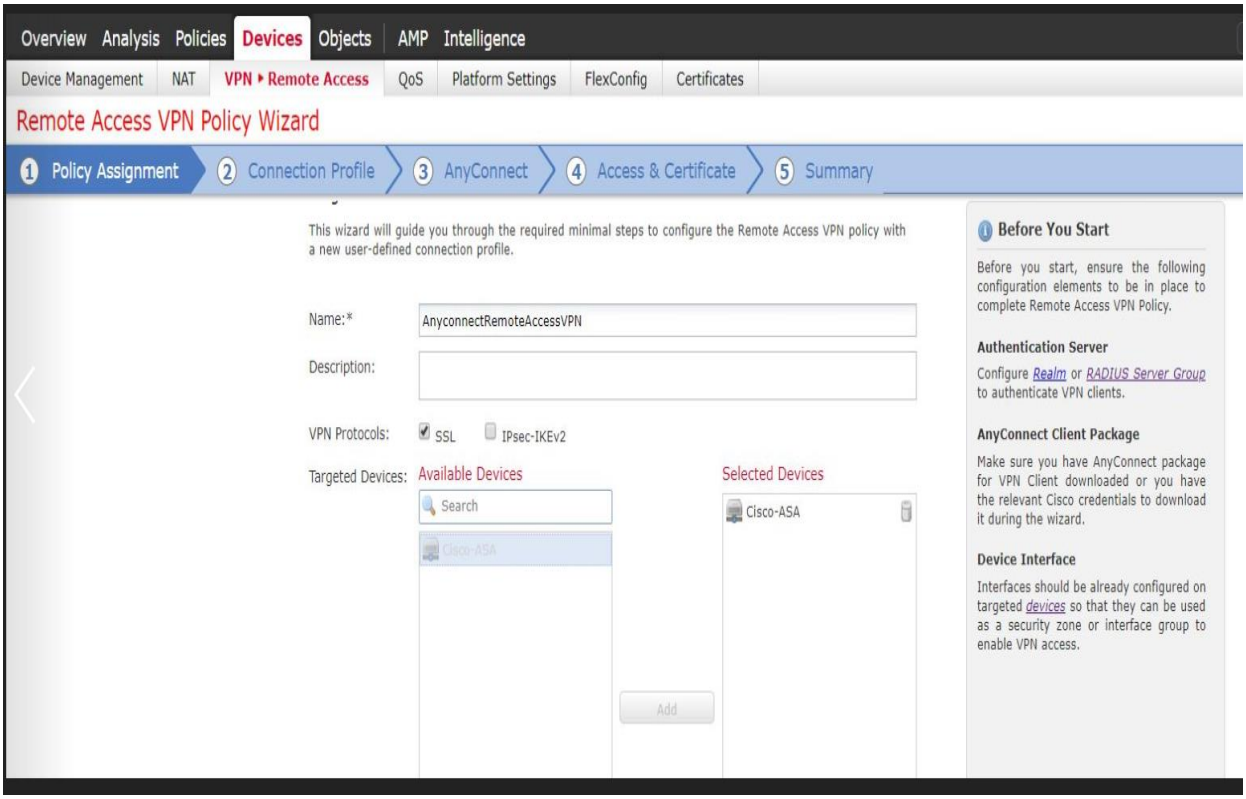


4. Click **Add Radius Server Group** > Enter a **Name** and **Description** > Hover the mouse to **Radius Servers** in the bottom menu >> Click on **+** to add one.
5. Enter the IP address of the Radius Server, a strong shared secret passphrase at the **New Radius Server screen**. Click **Save**.

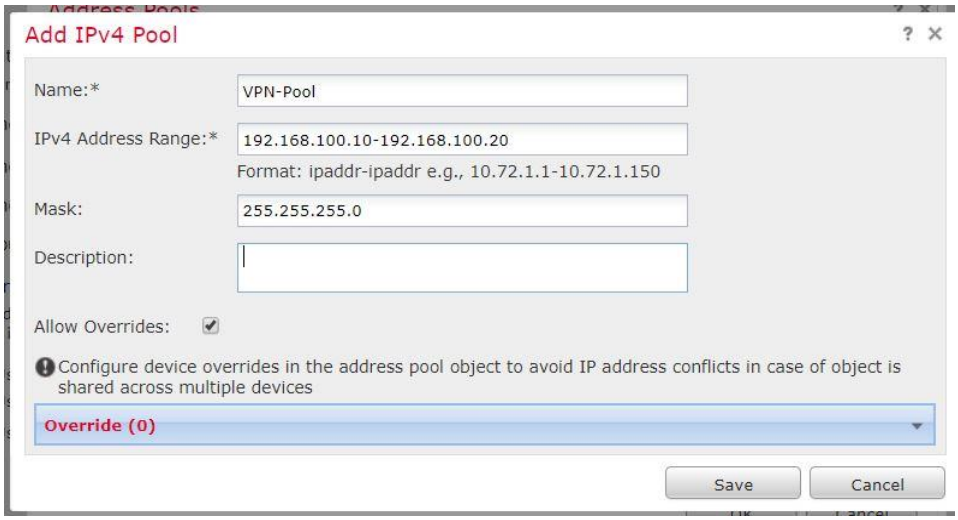


6. Click on the **Devices** menu > **VPN** > **Remote Access** > Wizard > **Add a new Configuration.** This will launch the Remote Access VPN Policy wizard

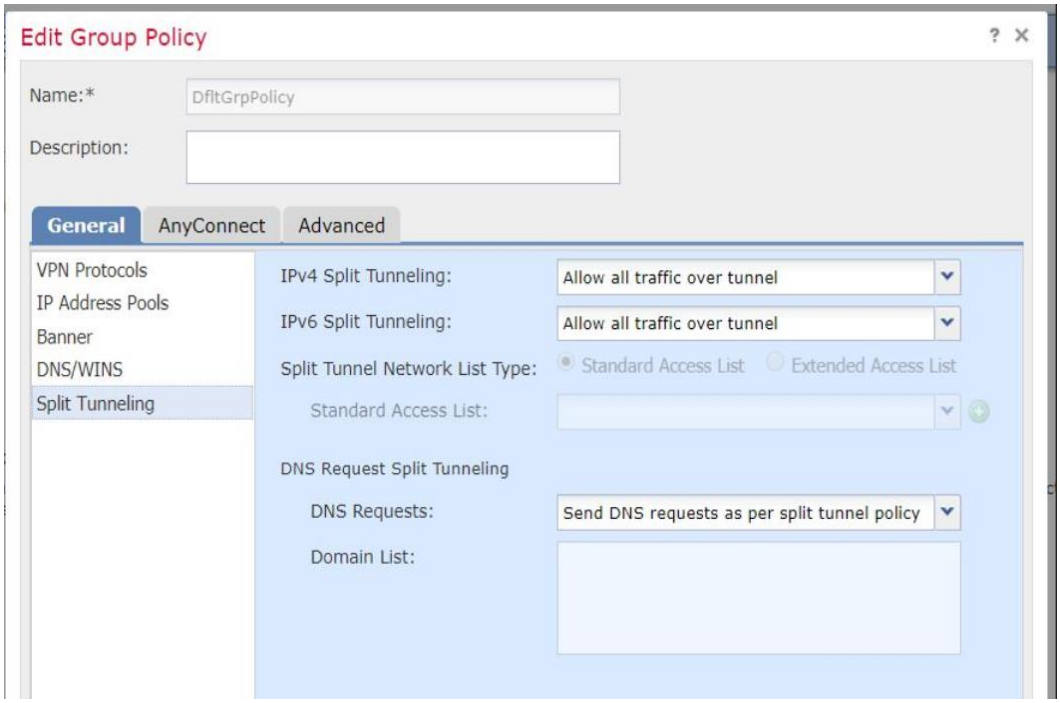
7. Perform the following actions on Policy Assignment
   a. Define a **Name, Description**.
   b. Select a protocol (SSL, IPSec-IKEv2). It is possible to select both.
   c. Move the appropriate firewall device under "**Available Devices**" (left-side) to "**Selected Devices**" right-side window



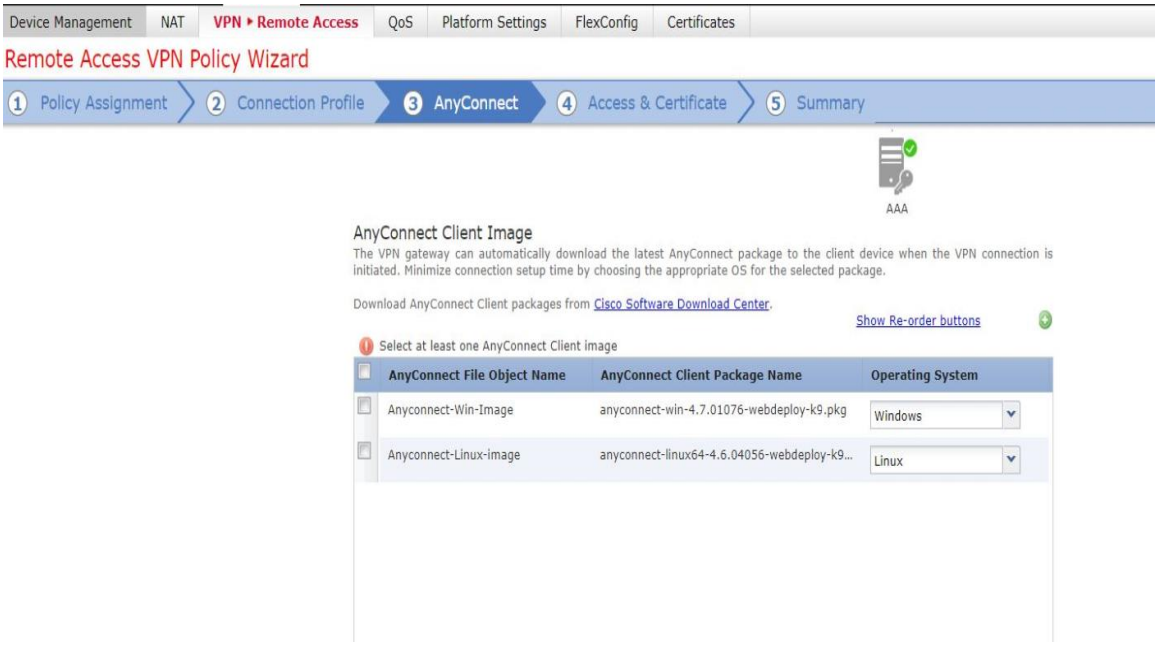
8. Setup a **Connection Profile** by entering the requested information
   a. Choose **AAA Only** as the **Authentication Method**
   b. Choose the name of Radius server under **Authentication Server**.
   c. Click on the **pencil** icon next to **Use IP Address Pool**, to create a New IPv4 Address Pool. For instance, the image below shows our ip-pool called as **VPN-Pool**



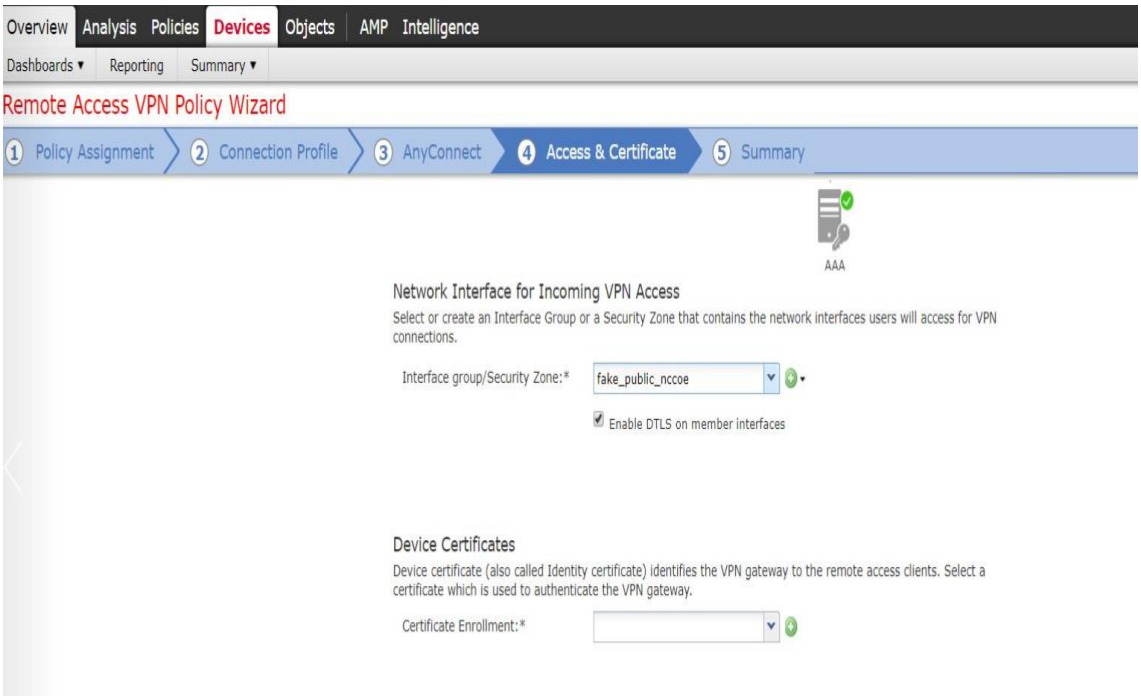
d. Create a new Group Policy or Edit the Default Group Policy under **Group Policy** as per your requirement. This is the policy name to be referenced on the Radius server setup on Windows.
For reference, the following changes were put in our Default Group Policy
- Under **General** > VPN Protocols > **SSL**
- Under **General** > **Banner** > Enter a custom welcome message
- Under **General** > **Split Tunneling** > Allow all traffic over tunnel (Split tunnel was disabled)
- Create a new Client Profile (if not already) under the **AnyConnect** tab
- Idle Session Timeout was set to 30 minutes Under **Advanced** > **Session Settings** Refer to the images below for reference.



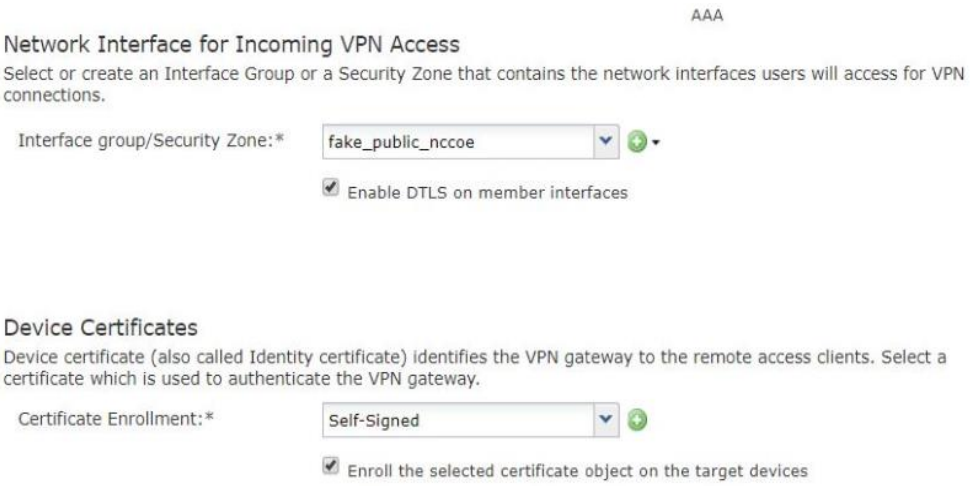
9. Select the AnyConnect Image for OS Supported (Windows, Linux, MacOS) under the **AnyConnect** screen. Click on the + icon to manually upload a new installer image.



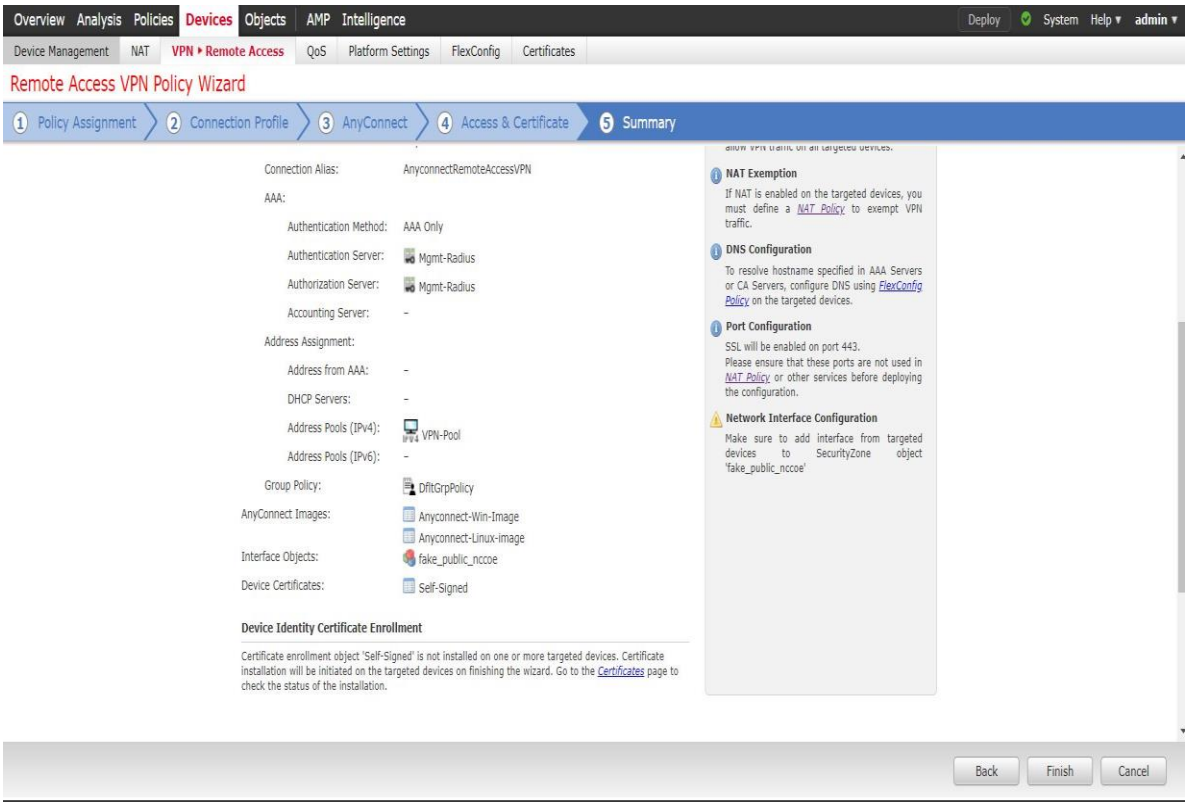
10. Configure the following items under the **Access & Certificate** screen:
    a. Select the **outside** firewall interface for the **Interface group/Security Zone** option



b. Select a certificate to authenticate the VPN gateway under **Device Certificates.** This can be an existing one or click + to create a self-signed certificate. A self-signed certificate was used in our environment.



11. Review the **Summary page**. If all settings appear correct click **Finish** to apply them



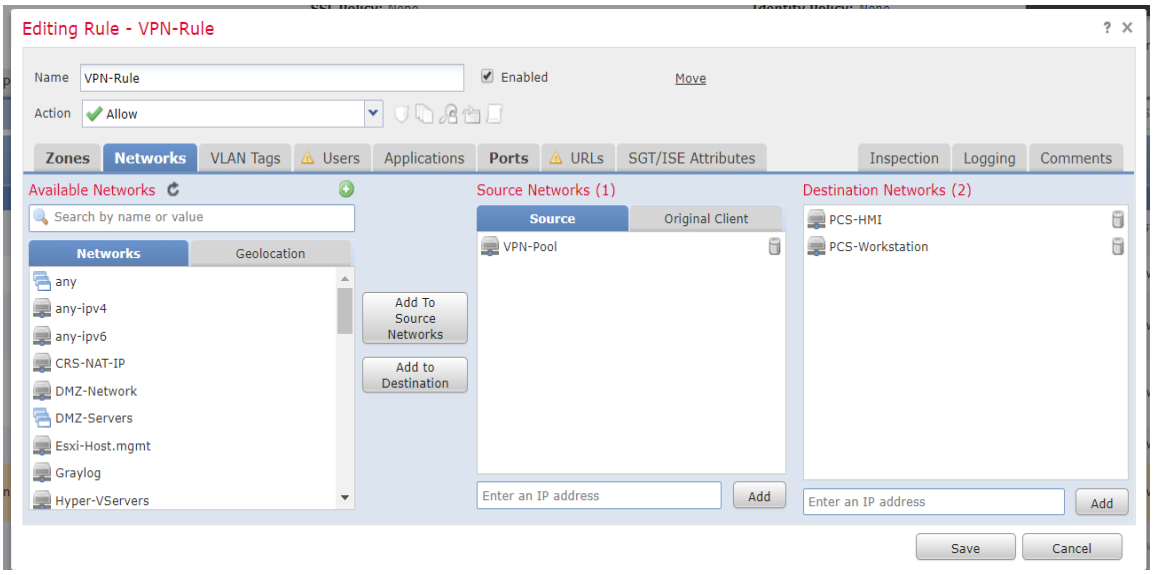
4.8.5.4 Additional configuration

Once the Remote Access VPN policy wizard is completed, the following configurations need to be put in place for the remote access VPN to work on all device targets:

- Access Control policy
- Device Certificate
- NAT Exemption

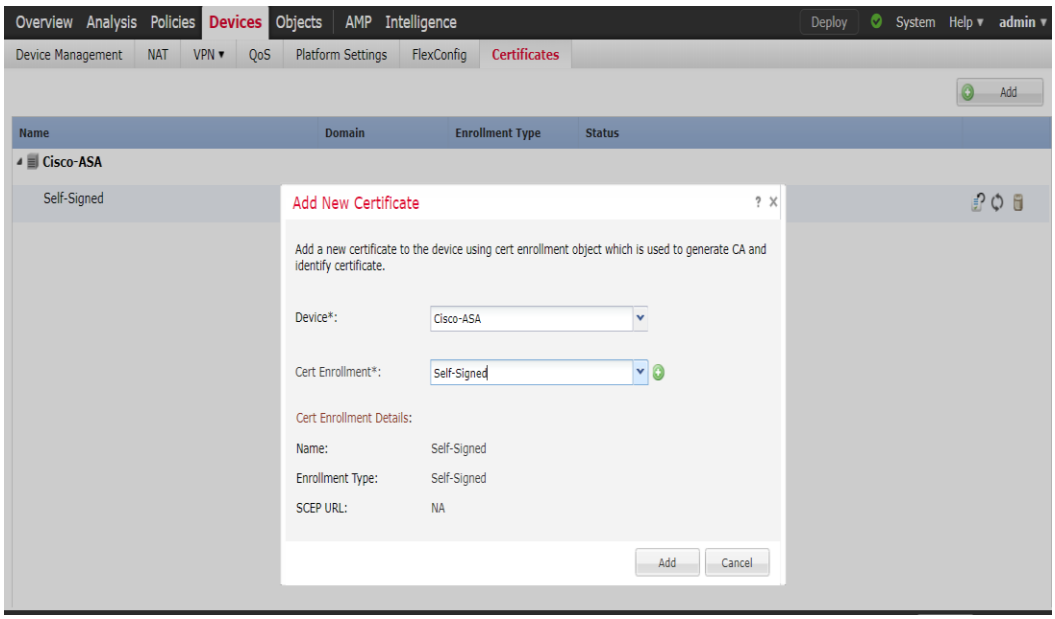
1. Create an Access Control Policy:
   a. Define an ACL rule to allow VPN traffic on to whichever network segments you wish to permit.

      For example, the Image and the table below lists the details of an ACL rule put in place to allow VPN traffic from outside to only a couple of internal servers in the Process Control system over Remote Desktop Port 3389.



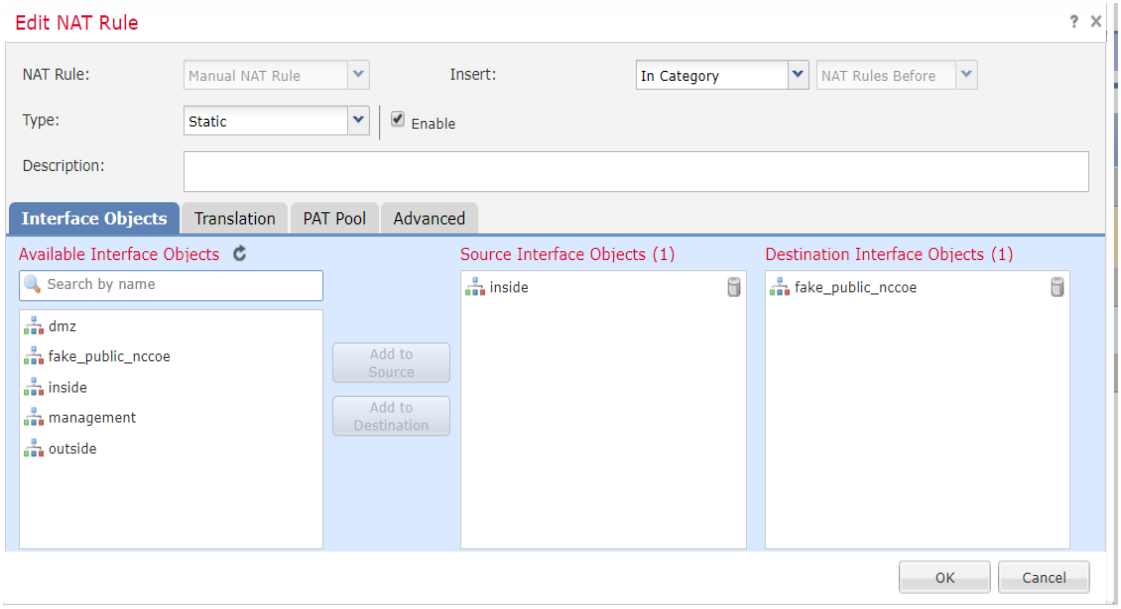
	Source	Destination	Selection
Zones	Outside	Inside	
Networks	VPN_Pool (Network)	HMI Server (Host) and Workstation (Host)	
Ports	Any	3389 TCP	
Action			Allow
Inspection			Enabled. Balanced connectivity over Security.

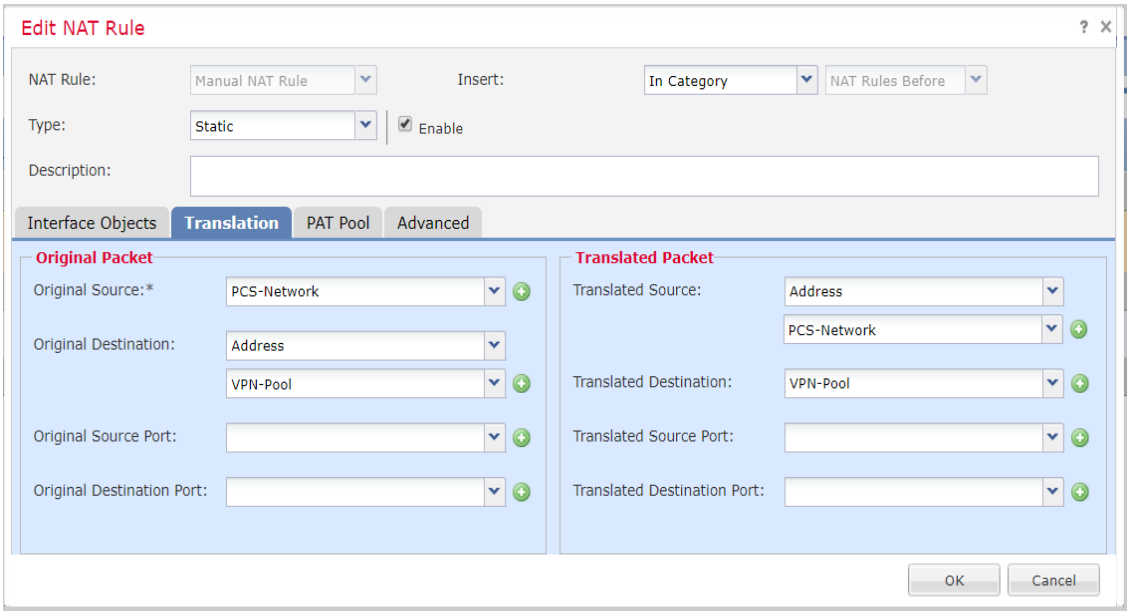
2. Create a Device Certificate
   a. Associate the self-signed or external certificate created earlier with the Firewall device.



3. Create a NAT Exemption rule as follows**:**
   a. Define a NAT rule to exempt VPN traffic assuming NAT is already enabled on firewall.
   b. Click on **Devices** Menu > **NAT** > **Select <NAT Policy>** > **Add Rule.**
   c. Add the Source, Destination interface objects.
   d. Select the Translation settings under **Translation** as per your environment.
   e. Select **Do not proxy ARP on Destination Interface** under Advanced tab

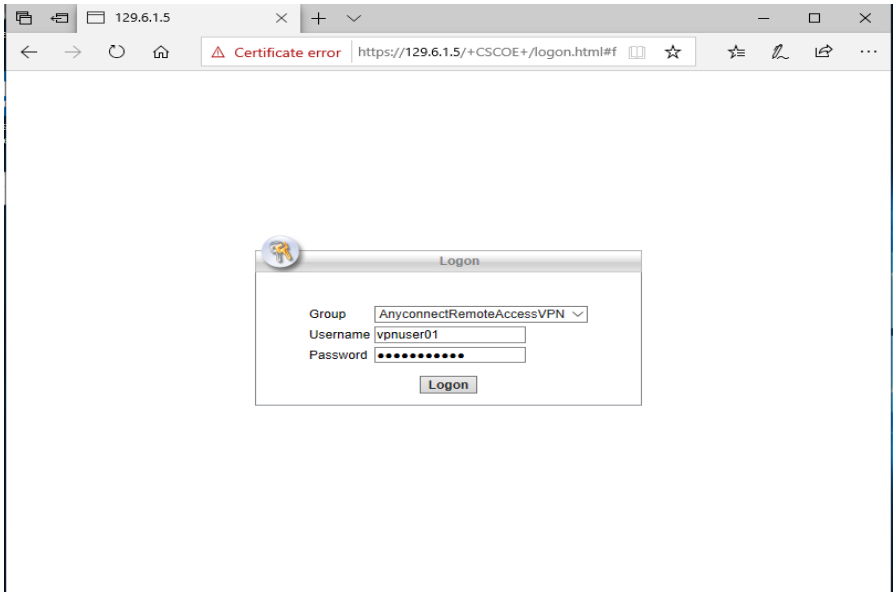
The images below show a NAT Rule created to exempt VPN Traffic.



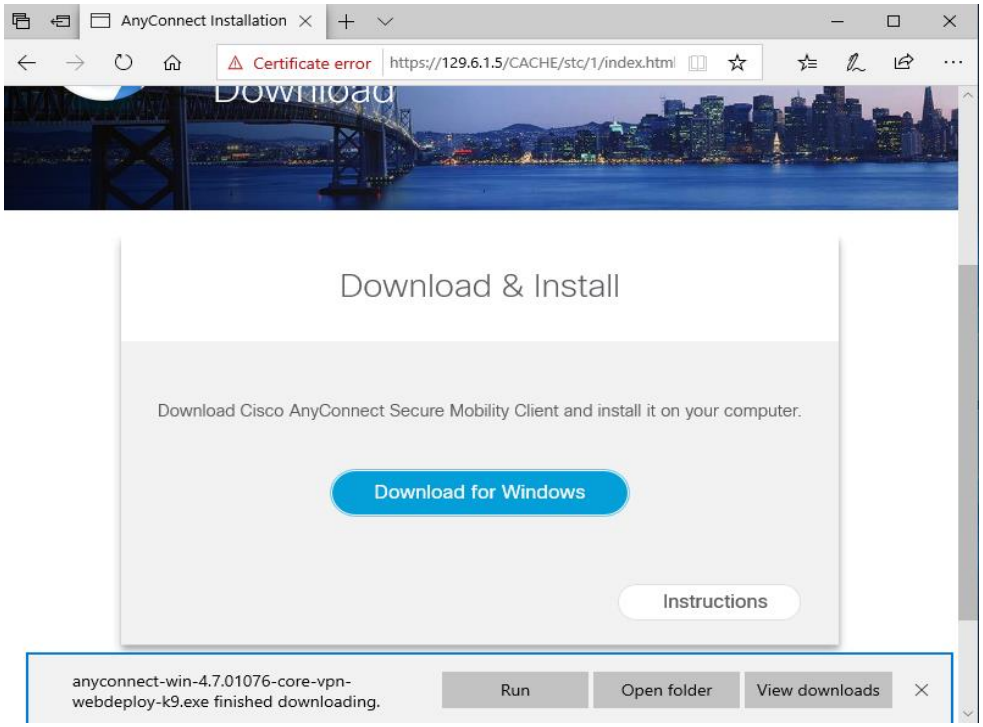


4.8.5.5 Client Connection

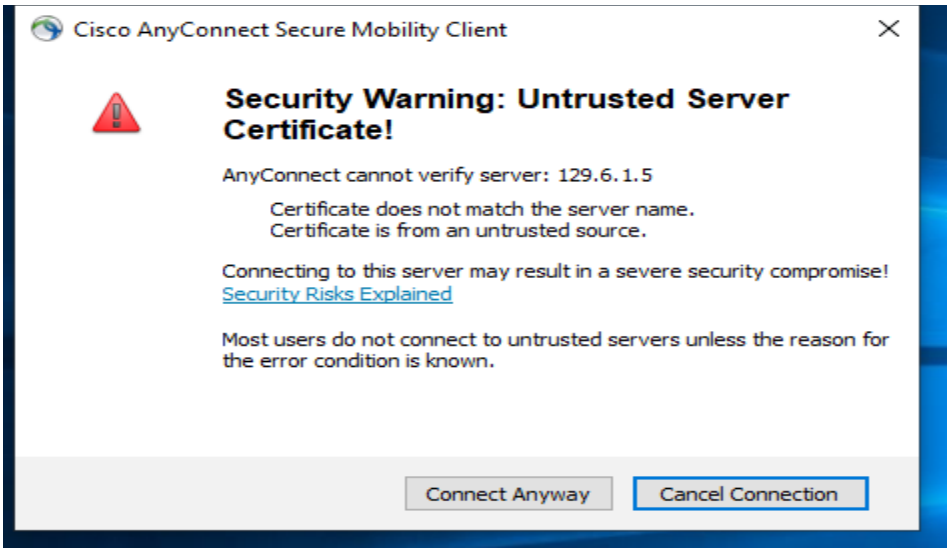
1. Install the VPN software (for a new Windows client system) as follows:
   a. Open a web browser and navigate to the IP address of the Outside interface of the Firewall.
   b. Enter the Active Directory user credentials at the logon prompt.



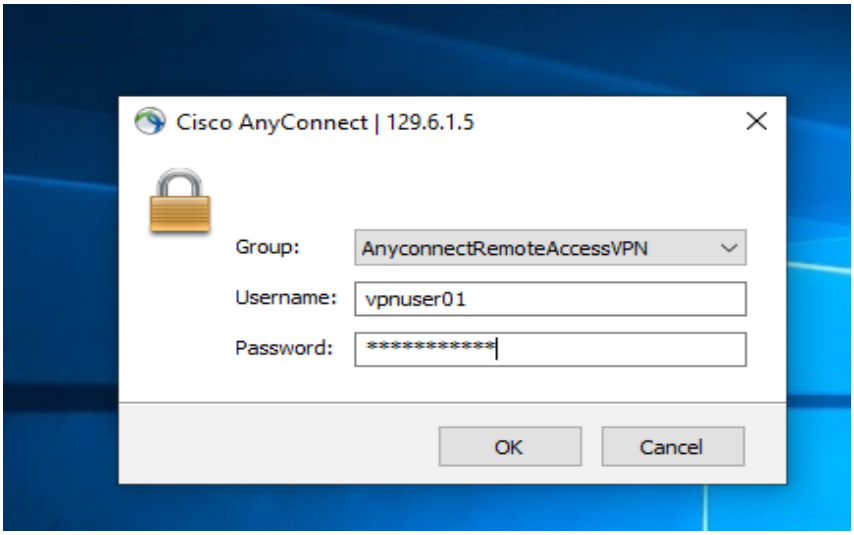
   c. Download the AnyConnect client software. Run the .exe to install it.



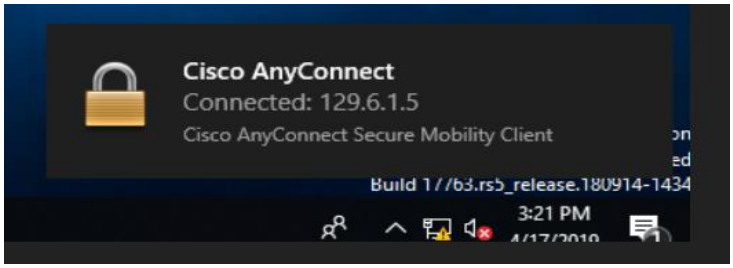
2. Double click on the Cisco AnyConnect VPN in the System-tray to launch the software. Click **Connect**.
3. Click **Connect Anyway** if prompted on the Untrusted Certificate warning message when using a self-signed certificate as in our case. **Note**: This warning message will not pop-up when using a public CA certificate.



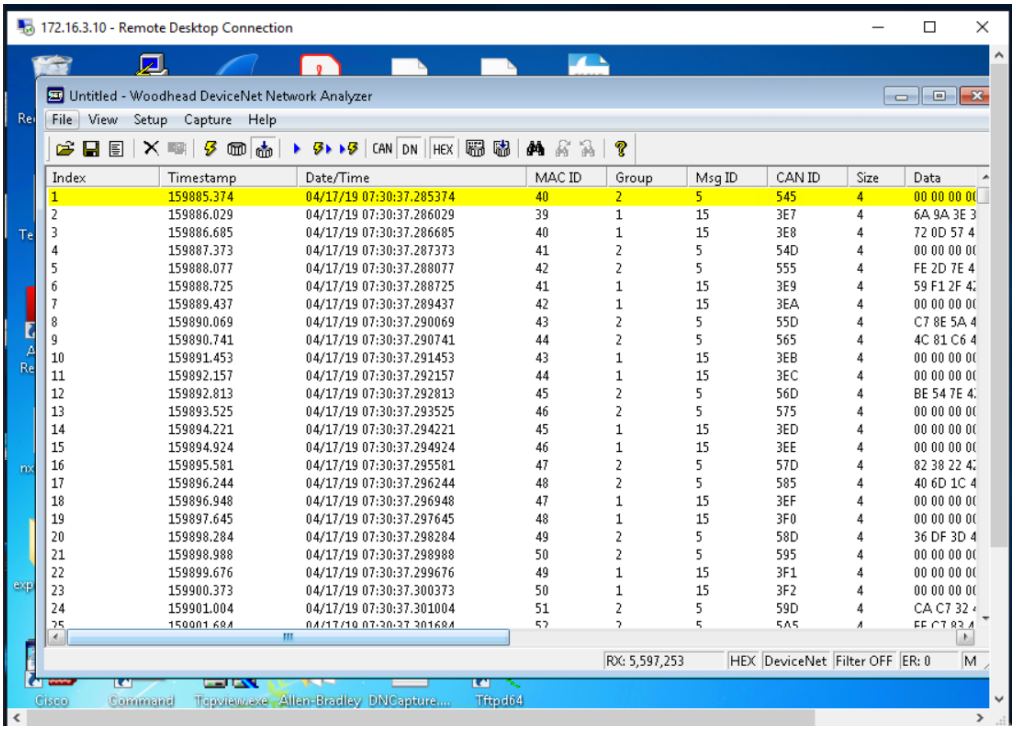
4. Enter the AD user credentials.



5. Look out for the pop-up message showing the Client as Connected.



6. Login to any of the hosts as permitted by the ACL rule setup earlier.
   For instance, upon establishing the connection, the two servers in Process Control System whitelisted earlier in the ACL Rule were accessed using RDP to perform Remote Maintenance.



4.8.5.6 Additional Information

Cisco AnyConnect VPN[83]
Cisco ASA VPN User Authentication[84]

[83] https://www.cisco.com/c/dam/en/us/products/collateral/security/anyconnect-secure-mobility-client/at_a_glance_c45-578609.pdf
[84] https://www.cisco.com/c/en/us/support/docs/security/asa-5500-x-series-next-generation-firewalls/117641-config-asa-00.html

4.8.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Cisco AnyConnect VPN tool while the manufacturing system was operational:

Experiment PL012.1- VPN connection from testbed LAN
In this experiment, a remote user was accessing the HMI from a remote computer through the VPN connection. A remote computer was first connected to the testbed LAN through the VPN, then used the Remote Desktop to connect to the HMI computer to access the HMI screen.

Although there was slightly increased network traffic between the testbed LAN and the PCS system due the Remote desktop session, there was no significant performance impact observed in the PCS system. The packet round trip time between the HMI and OPC remained mostly constant with and without the VPN connection.

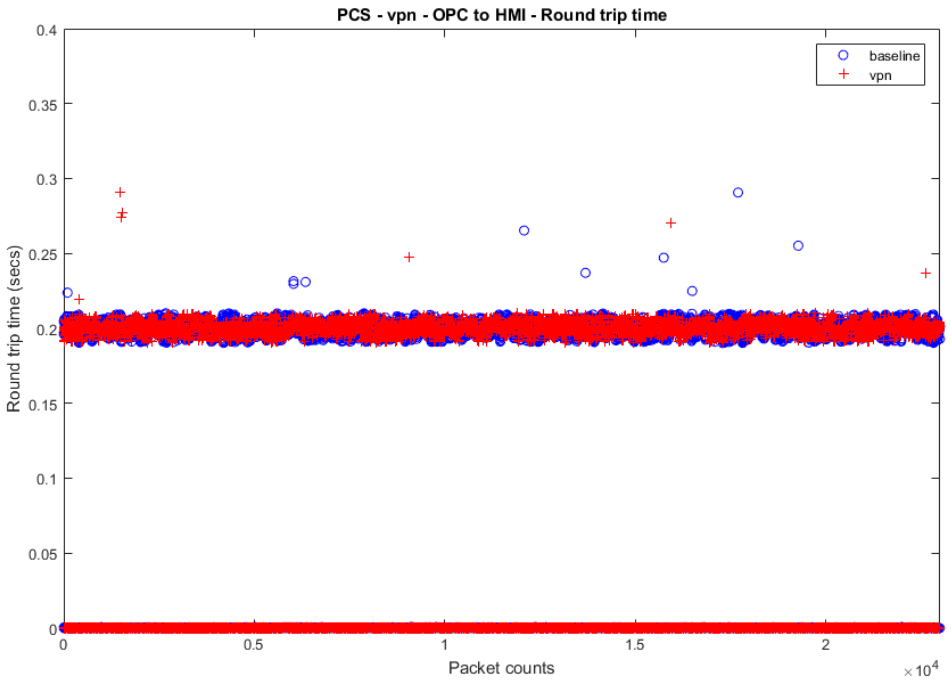


Figure 4-12 Plot of packet round trip time from OPC to HMI computer during the use of VPN connection from a remote computer

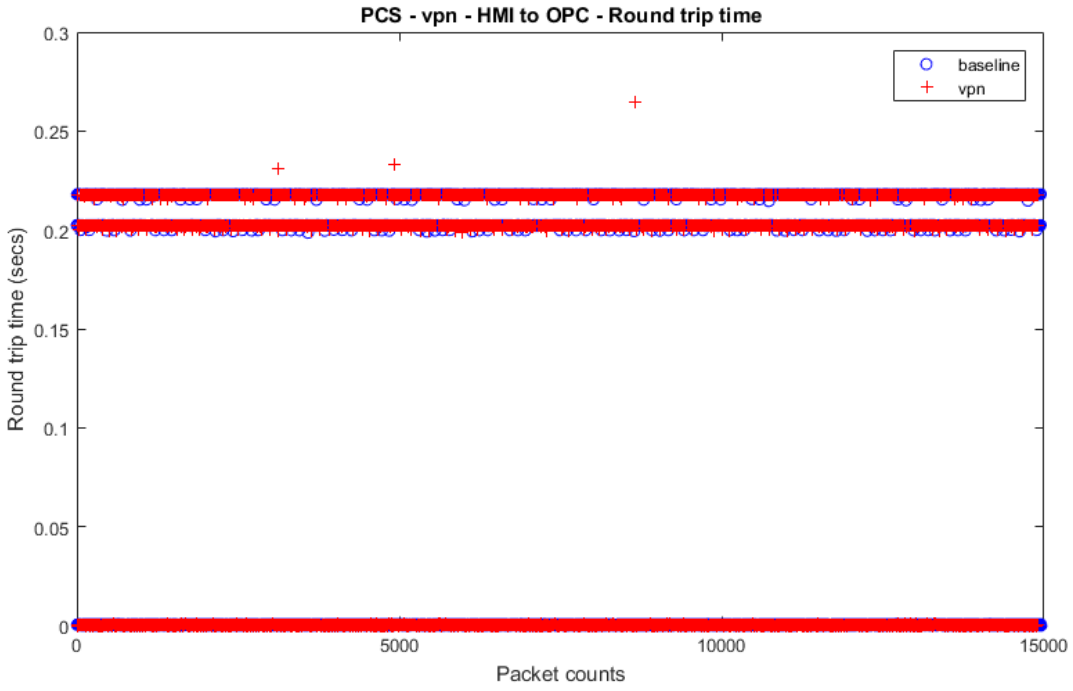


Figure 4-13 Plot of packet round trip time from HMI to OPC computer during the use of VPN connection from a remote computer

The manufacturing process also remained stable without any significant performance impact observed. The reactor pressure and product flow rate remained constant with and without the VPN connection.

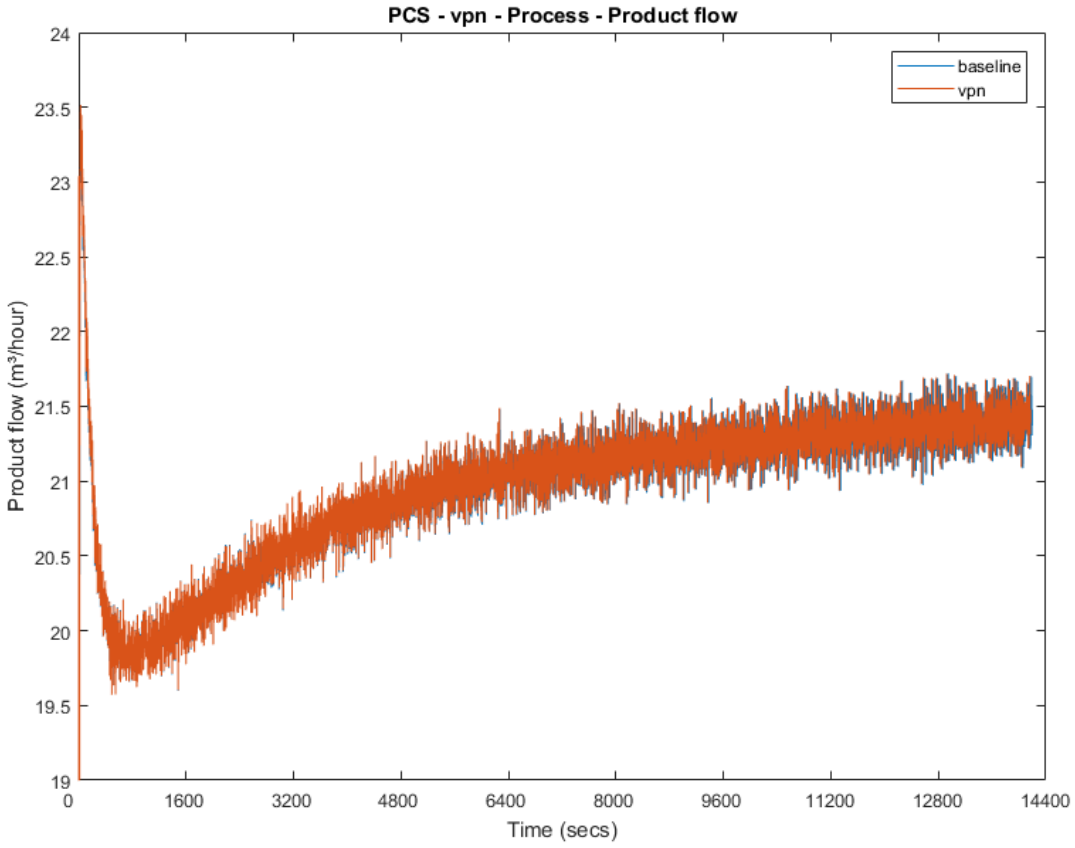


Figure 4-14 Manufacturing process product flow rate during the use of VPN connection from a remote computer

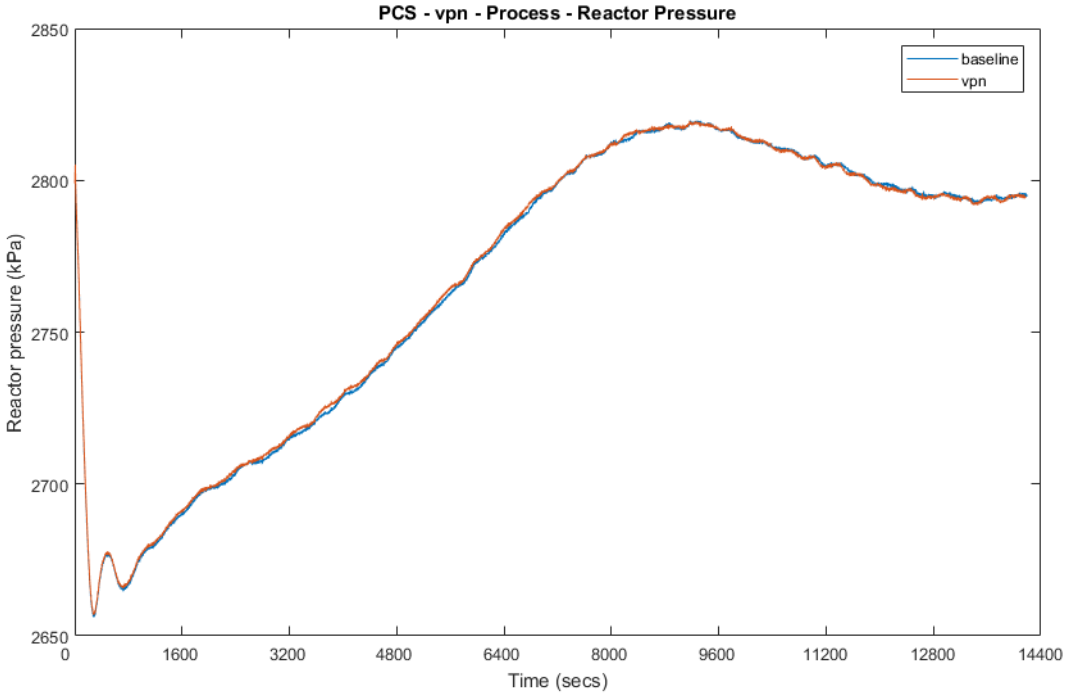


Figure 4-15 Manufacturing process reactor pressure during the use of VPN connection from a remote computer

4.8.7 Links to Entire Performance Measurement Data Set

- **Cisco VPN KPI data**
- **Cisco VPN measurement data**

4.9 Microsoft Active Directory

4.9.1 Technical Solution Overview

Active Directory (AD) is a directory service developed by Microsoft for Windows domain networks. A directory is a hierarchical structure that stores information about objects on the network. A directory service, such as Active Directory Domain Services (AD DS), provides the methods for storing directory data and making this data available to network users and administrators. For example, AD DS stores information about user accounts, such as names, passwords, phone numbers, and so on, and enables other authorized users on the same network to access this information. A server running Active Directory Domain Services (AD DS) is called a domain controller. It authenticates and authorizes all users and computers in a Windows domain type network—assigning and enforcing cybersecurity policies for all computers and installing or updating software. Active Directory uses Lightweight Directory Access Protocol (LDAP) versions 2 and 3, Microsoft's version of Kerberos and DNS.[85]

Points to consider:

- Cost of infrastructure can get high.
- Requires expertise to setup and maintain. Setup involves detailed planning.
- It is prone to being hacked.

4.9.2 Technical Capabilities Provided by Solution

Microsoft Active Directory provides components of the following Technical Capabilities described in Section 6 of Volume 1:

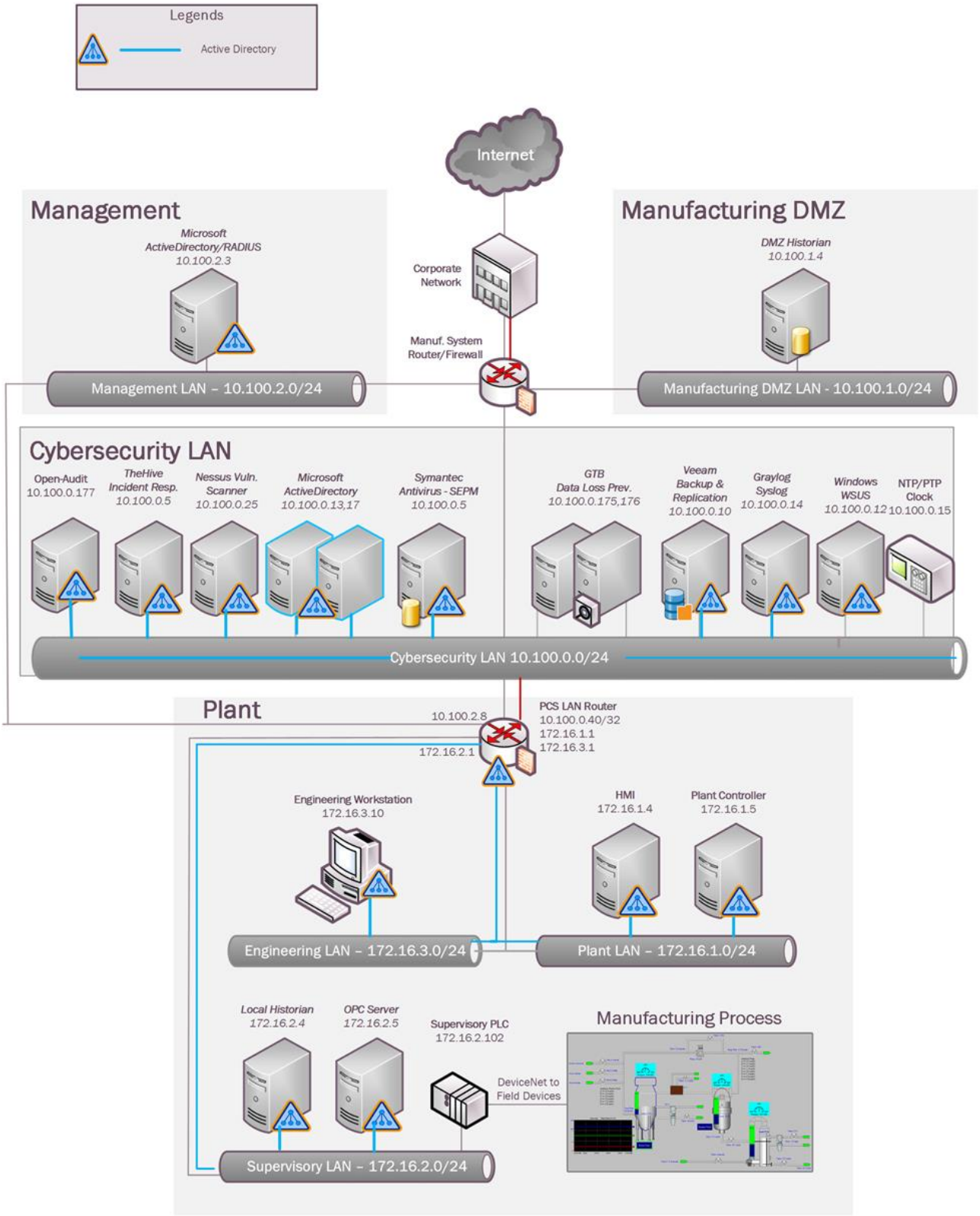
- Credential Management
- Authentication and Authorization

4.9.3 Subcategories Addressed by Implementing Solution

PR.AC-1, PR.MA-1, PR.MA-2, PR-PT-3, PR.PT-4, DE.CM-3

[85] https://docs.microsoft.com/en-us/windows-server/identity/ad-ds/get-started/virtual-dc/active-directory-domain-services-overview

4.9.4 Architecture Map of Where Solution was Implemented



4.9.5 Installation Instructions and Configurations

Details of the environment:

Hostname	Roles	Domain Name	Hardware Details
LAN-AD	Active Directory, DNS Server	LAN.lab	Hyper-V Virtual Machine (Generation 2): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 70 GB • Network: 1 network adapter • OS: Windows 2012 R2
LAN-AD02	Active Directory, DNS Server	LAN.lab	Hyper-V Virtual Machine (Generation 2): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 70 GB • Network: 1 network adapter • OS: Windows 2012 R2
Mgmt-AD	Active Directory, DNS, Network Policy Server (Radius)	Mgmt.lab	Hyper-V Virtual Machine (Generation 2): • Processors: 2 virtual cores • Memory: 4 GB • Disk space: 40 GB • Network: 1 network adapter • OS: Windows 2012 R2

4.9.5.1 Environment Setup

Our setup consists of two separate Active Directory (AD) domain environments; one for the Cybersecurity -LAN network and other for the Management network. For security reasons, the AD domain in the Cybersecurity LAN network is separate from the domain of the Management network. This Domain Controller (DC) in the Management network has Windows NPS (Radius) services installed for authenticating the network devices.

1. Two virtual machines, each running Windows 2012 R2 were setup on a Hyper-V host server of the Cybersecurity LAN network for authenticating Windows/Linux devices. The hardware specifications of these are described in the table above.
2. One virtual machine running Windows 2012 R2 was setup in the Management network for authenticating VPN users and network devices such as boundary routers.
3. The guest OS IP information of these servers was set as follows:

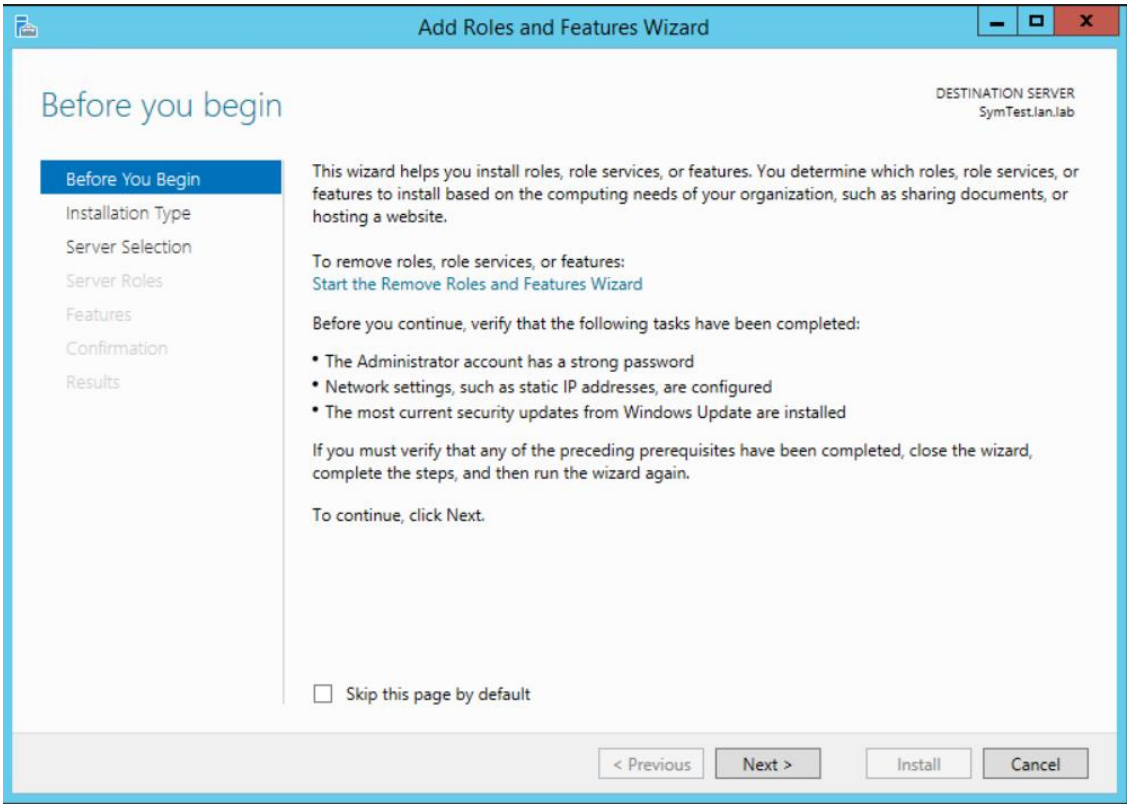
```
Hostname: LAN-AD.lan.lab
IP address: 10.100.0.5
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:127.0.0.1, 10.100.0.13

Hostname: LAN-AD02.lan.lab
IP address: 10.100.0.13
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17,127.0.0.1

Hostname: Mgmt-AD.mgmt.lab
IP address: 10.100.2.3
Gateway: 10.100.2.1
Subnet Mask: 255.255.255.0
DNS:127.0.0.1
```

4.9.5.2 Installing Active Directory Domain Services & DNS Server

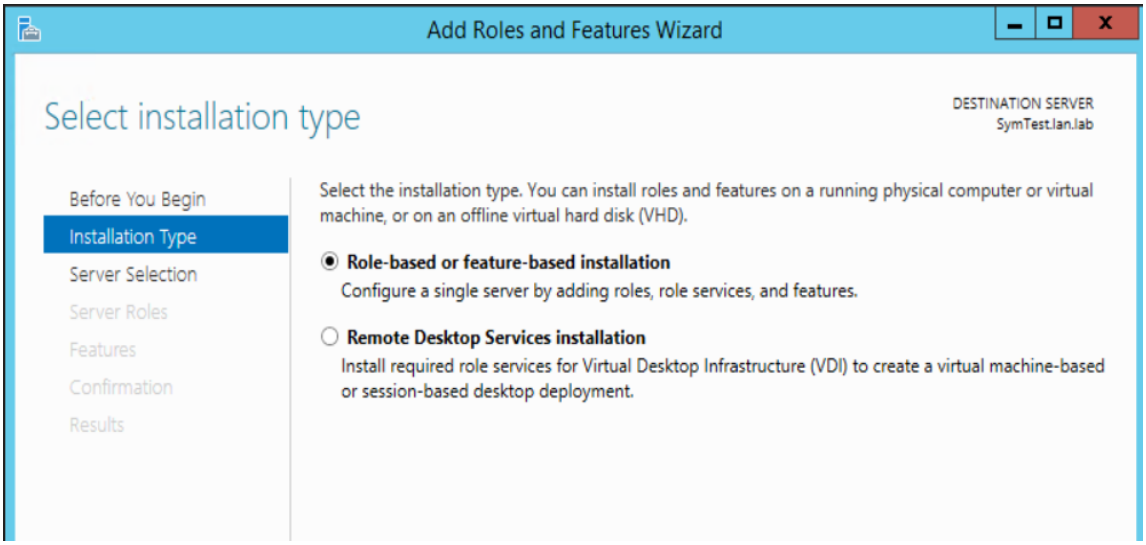
Prerequisites

Windows 2012 R2 server (preferably two for redundancy) up to date on patches, static IP address assigned with primary DNS server set to 127.0.0.1 (localhost)

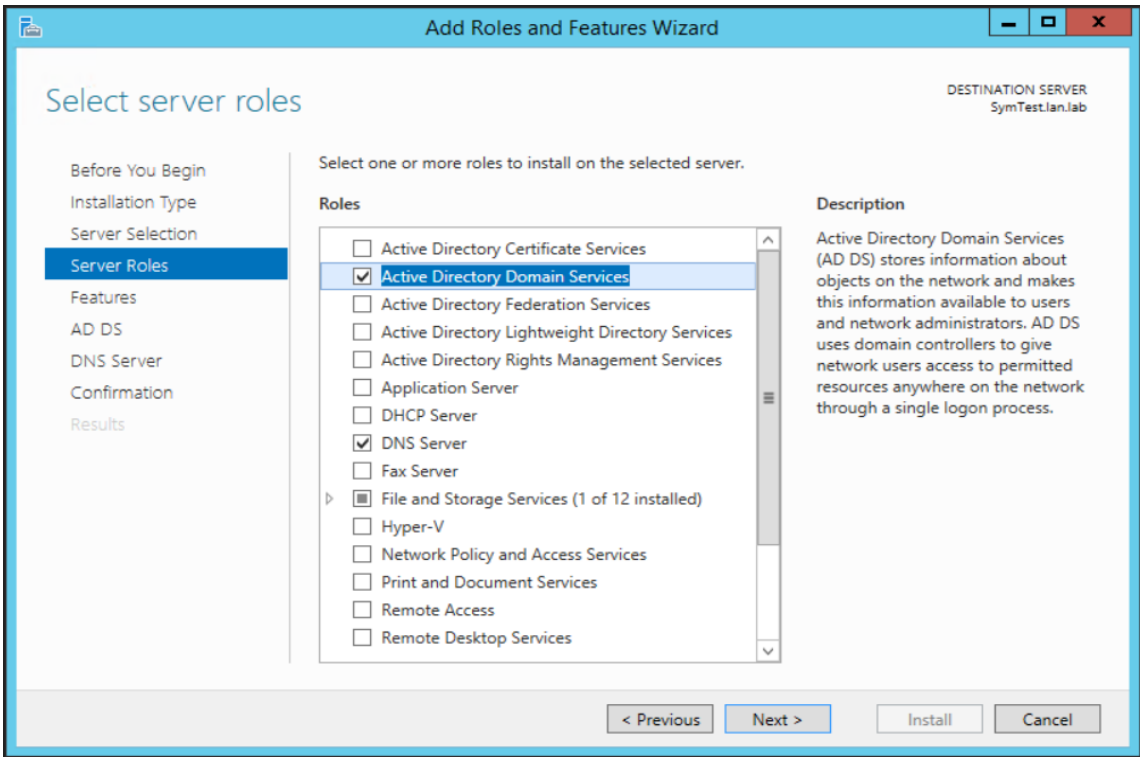
1. Launch the Windows **Server Manager** and click on **Add Roles and Features**
2. Click "**Next**" at the first page as shown below



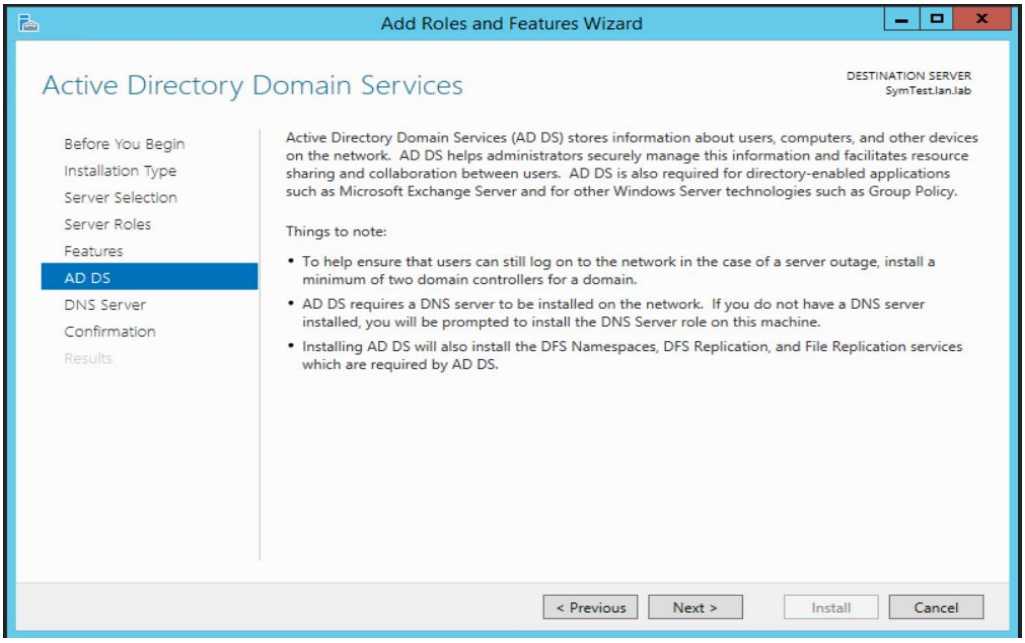
3. Select **Role Based or Feature Based Installation** under Installation Type



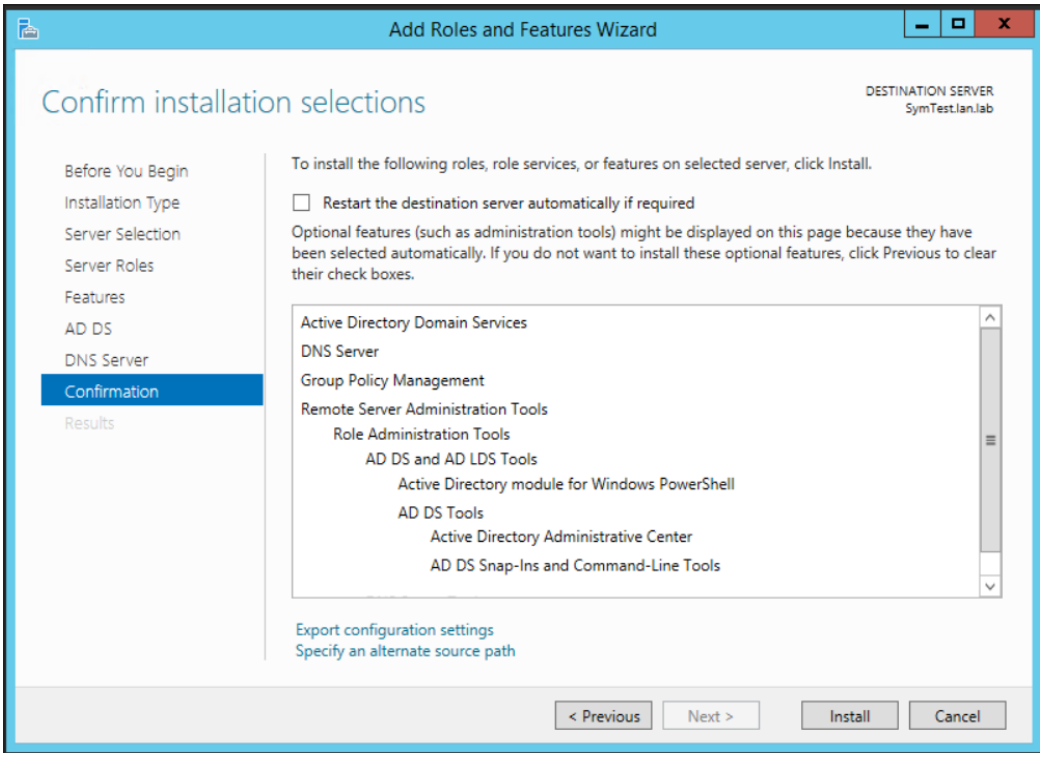
4. Select **Active Directory Domain Services** and **DNS Server** to install. Click **Next.**



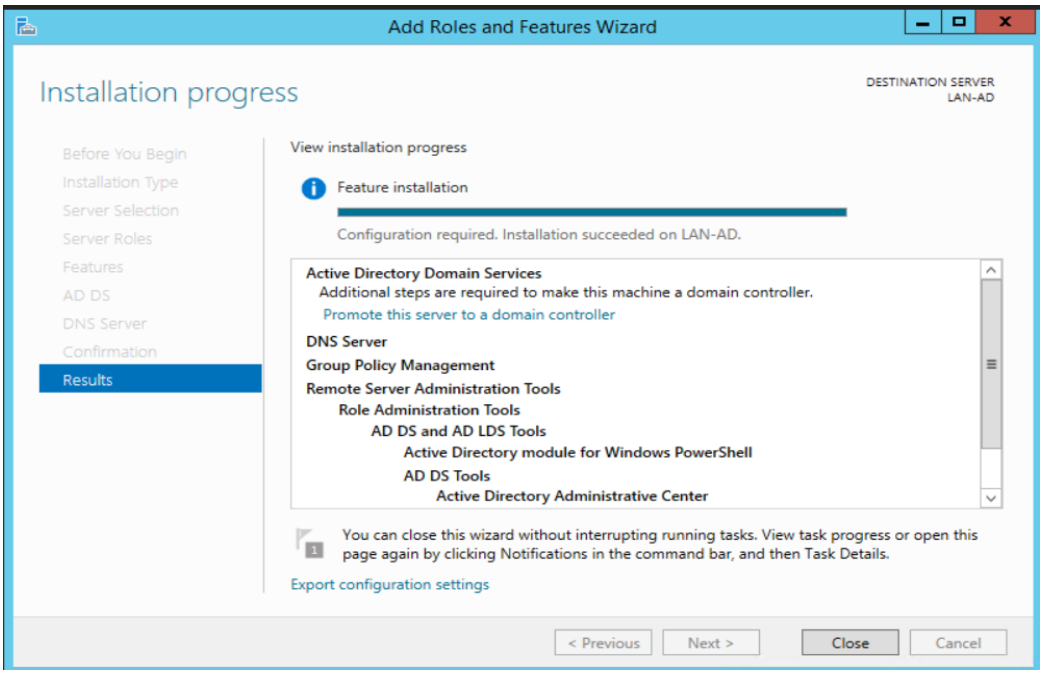
5. Click **Next** on the **Features** screen, leave the default options selected,
6. Click **Next on the AD DS** screen and the following **DNS Server** screen as well.



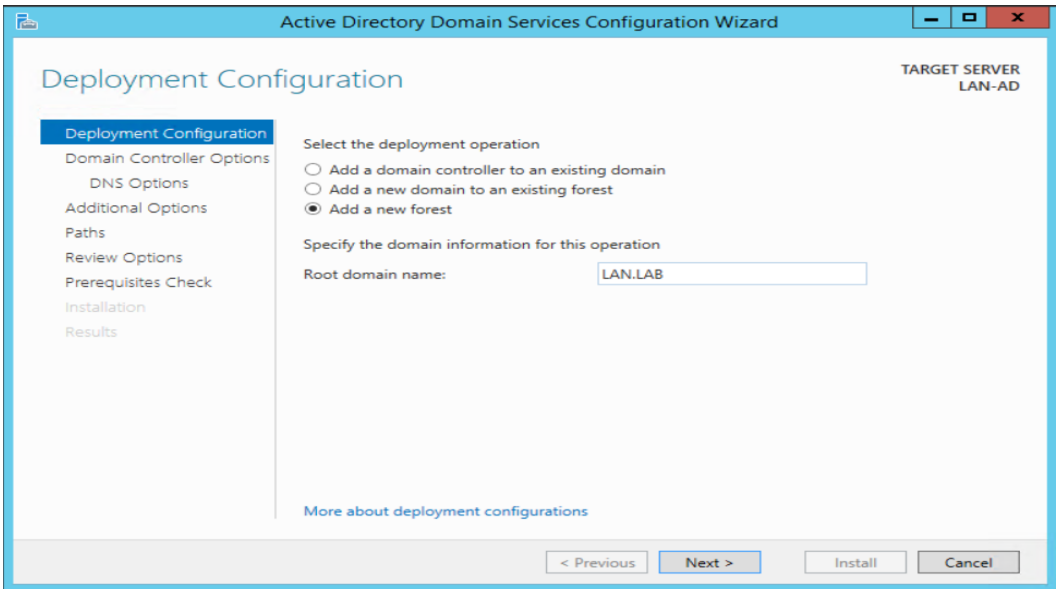
7. Verify your settings on the **Confirmation** screen. Click **Install** to proceed.



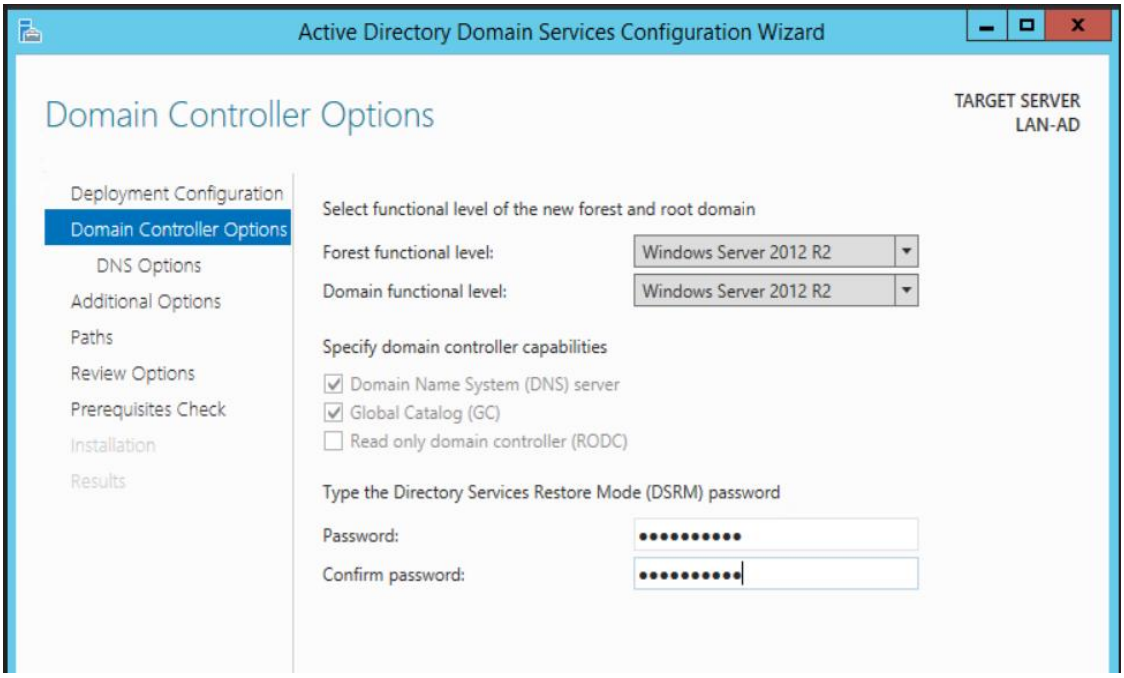
8. Wait till the installation process completes and shows an **Installation succeeded** message. Hit **Close** button.



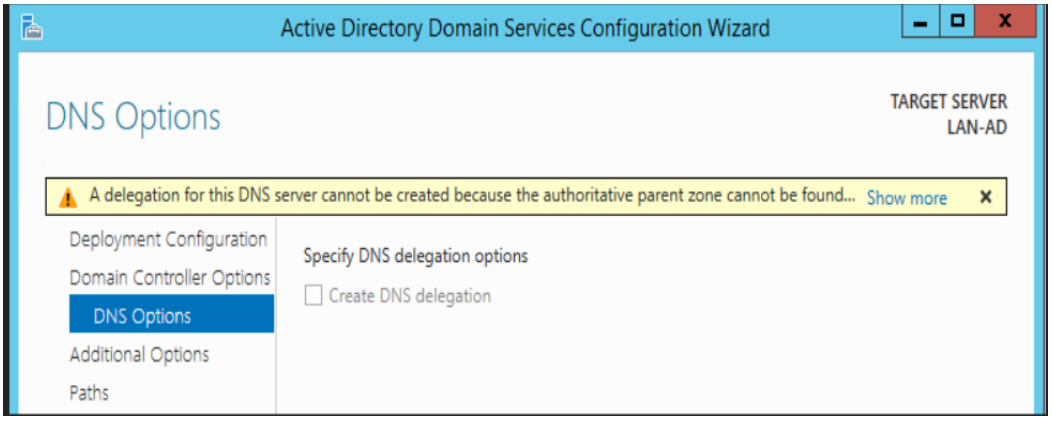
9. Launch **Server Manager** again and click on **Promote this server to a domain controller**.
10. Select **Add a new forest** on the **Deployment Configuration** step, as this would be a new domain controller in a new forest. Mention a **Root Domain name** as applicable to your environment.



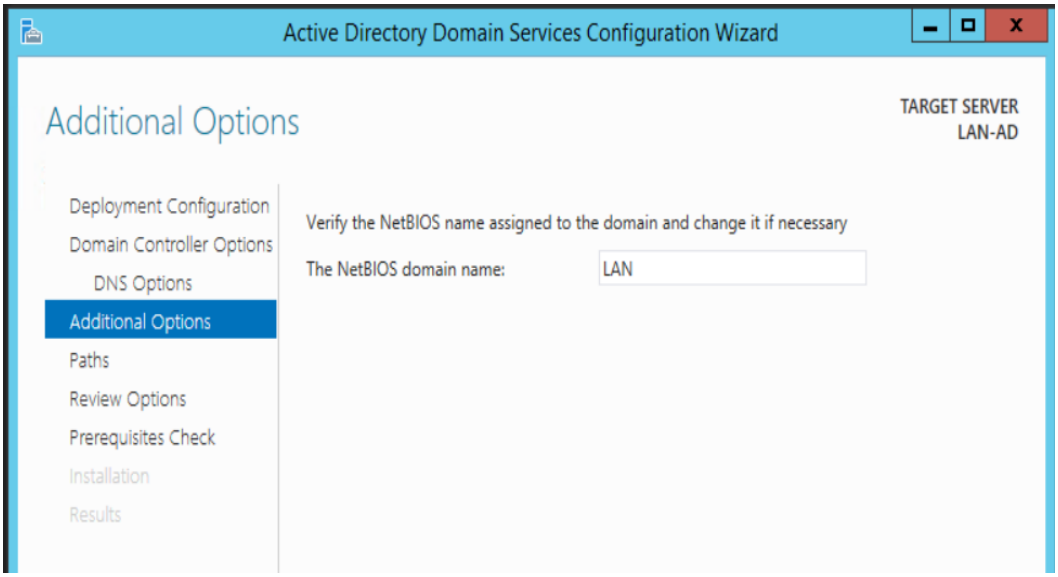
11. Set a **Directory Services Restore Mode** password in the next step. Click **Next**



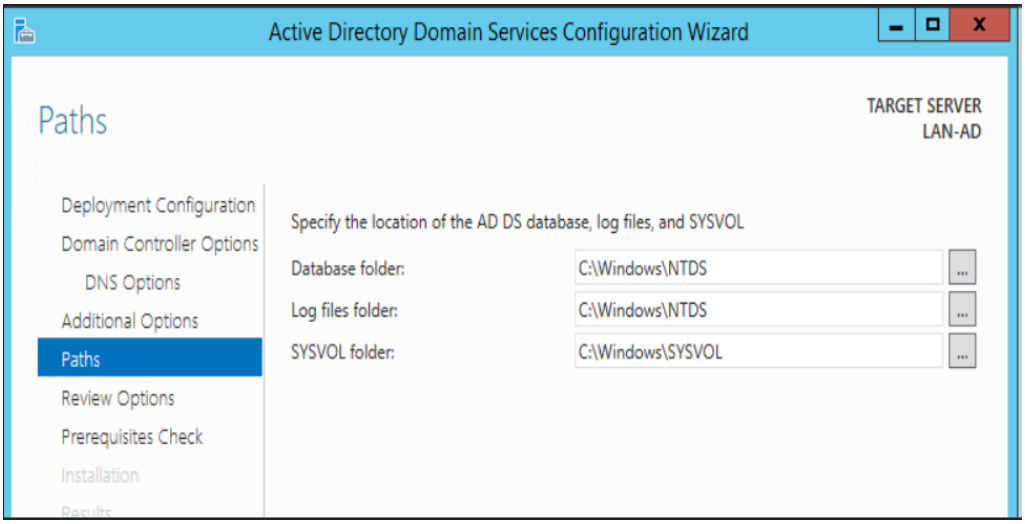
12. Under "**DNS Options**" leave the default options selected. Click **Next**



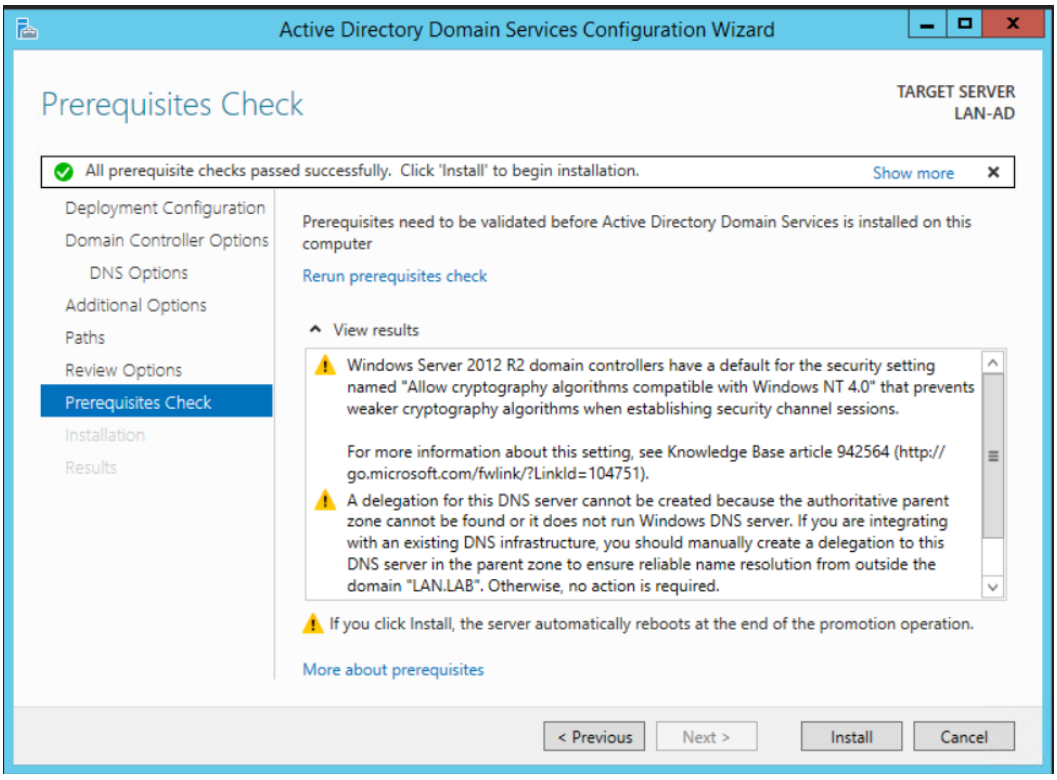
13. Confirm the NETBIOS domain name under **Additional Options**. Click **Next.**



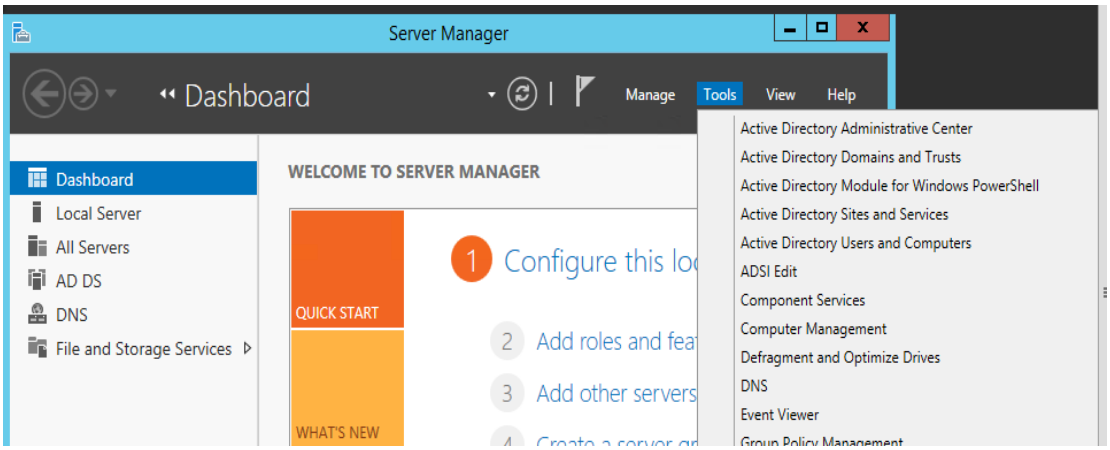
14. Leave the default folder paths as it is Under **Paths**. Click **Next**



15. Confirm all the settings On the **Review Options** page. Click **Next**.
16. Click Install on the **Prerequisites Check** to launch the installation process. The server will auto reboot upon completion.



17. Login with domain administrator credentials upon reboot. Open **Server Manager** and click on **Active Directory Users and Computers** under Tools to manage your AD.



4.9.5.3 Joining Windows Systems to Active Directory Domain

1. Change the DNS settings on each client system to point to the IP address of the Domain Controller server.
2. Refer to the instructions[86] described for joining Windows clients to the Active Directory domain.
3. Reboot client system when done.

4.9.5.4 Matrikon OPC Server DCOM Configuration

The OPC server in the plant which is running a Matrikon OPC server requires advanced configuration to work with Active Directory. The Microsoft Distributed Component Object Model (DCOM) service plays a vital role in integration the OPC server with AD. Having the correct DCOM settings in place when using AD is critical for plant operations. We have followed the steps as per the Matrikon OPC guide [87] to apply the necessary DCOM settings.

Prerequisites

- All Windows systems participating need to be domain joined to the AD server.
- Ensure all systems are getting their time synced from the AD server and verify the time on each server is consistent with the time on the AD (Domain Controller). Time sync is critical.
- Verify TCP port 135 is open between all OPC clients and the OPC server.

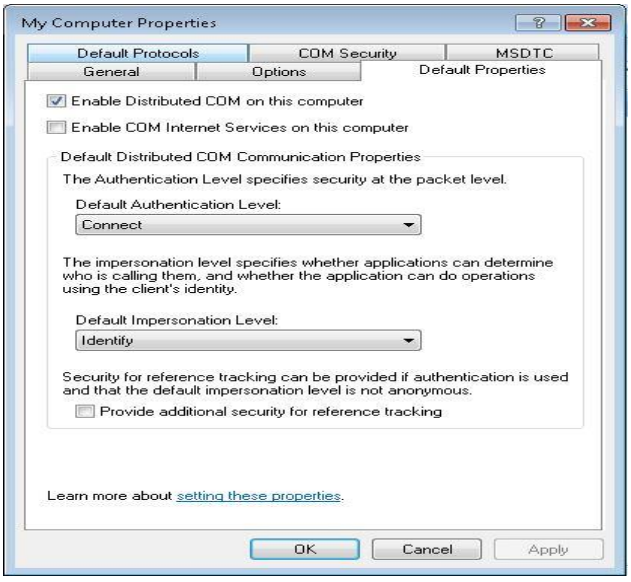
Systems taking part in the OPC setup:

Hostname	IP address	Roles	Administrators
OPC Server	172.16.2.5	OPC Server	opcadmin
Controller	172.16.1.5	OPC Server + Client	opcadmin

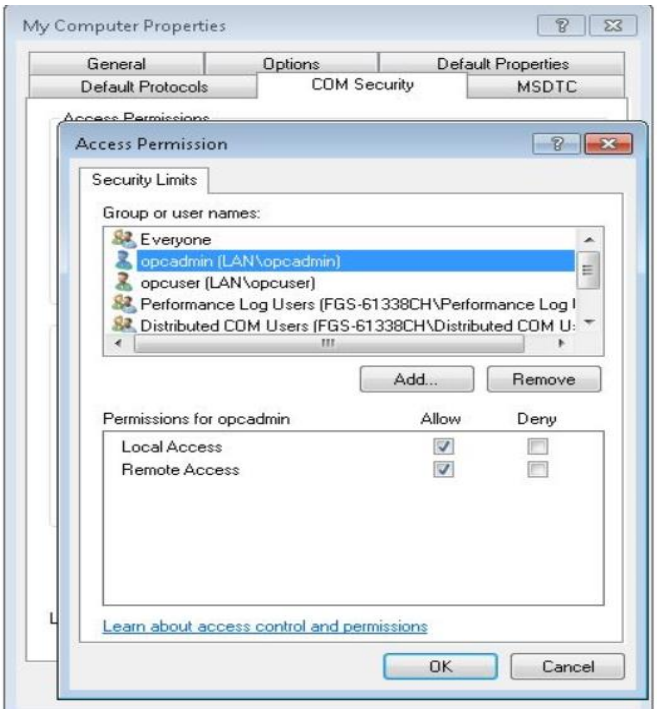
1. Create two domain users in AD. Assign one of the user accounts, administrative rights on the OPC servers. For instance, the following accounts **opcadmin** and **opcuser** were setup in our AD.
2. Add the **opcadmin** user to the Local Administrators group on the OPC Server and client.

[86] https://www.petri.com/join-a-domain-in-windows-7
[87] https://www.matrikonopc.com/downloads/1128/whitepapers/index.aspx

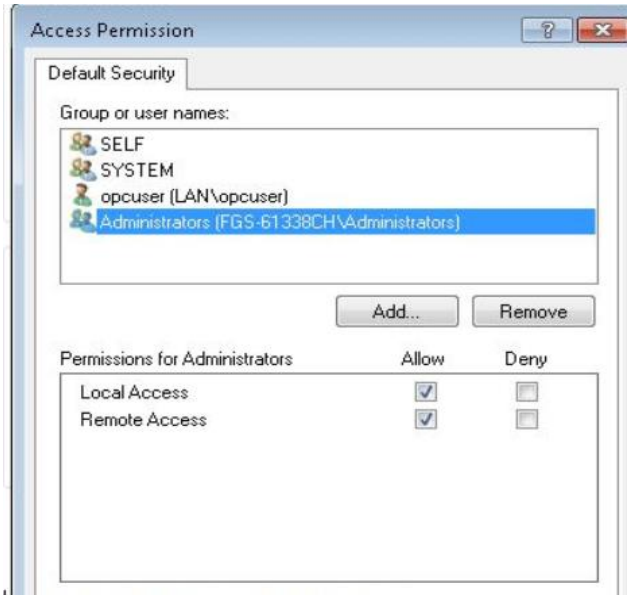
3. Make the following changes to DCOM properties on the **OPC Client system**
   a. Launch **Control Panel** > **Administrative Tools** > **Component Services** snap-in to open the DCOM console. Alternatively, you can also run `dcomcnfg`
   b. Expand **Console Root** > **Component Services** > **Computers.** Right-click My Computer > Properties, ensure the settings are as follows



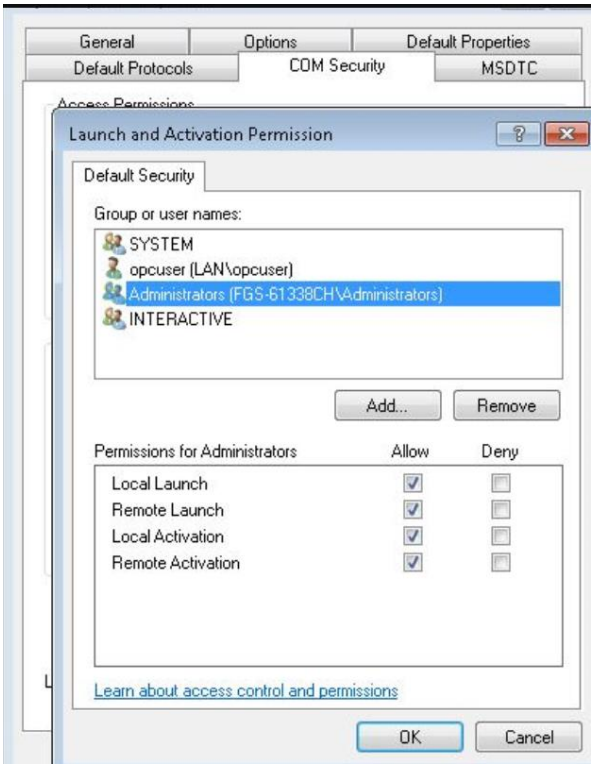
   c. Click on **COM Security** tab. Under **Access Permissions** > **Edit Limits** > Add the **opcadmin** user to the list and check the Allow boxes for **Local Access** and **Remote Access** categories. You can add the **opcuser** as well if needed and grant it Allow permission for only **Local Access**.



d. Click **Edit Default** button under A**ccess Permissions** window > Ensure that "<server-name>\Administrators" group has all the boxes checked. The **opcadmin** user was made part of this Administrators group earlier. If adding **opcuser**, grant it Allow for **Local Access** only



e. Click **Edit Default** button under the **Launch and Activation Permissions window** > Ensure the **Administrators** group has **ALLOW** Permissions for all 4 categories. The other **opcuser** should have ALLOW only for **Local Launch**

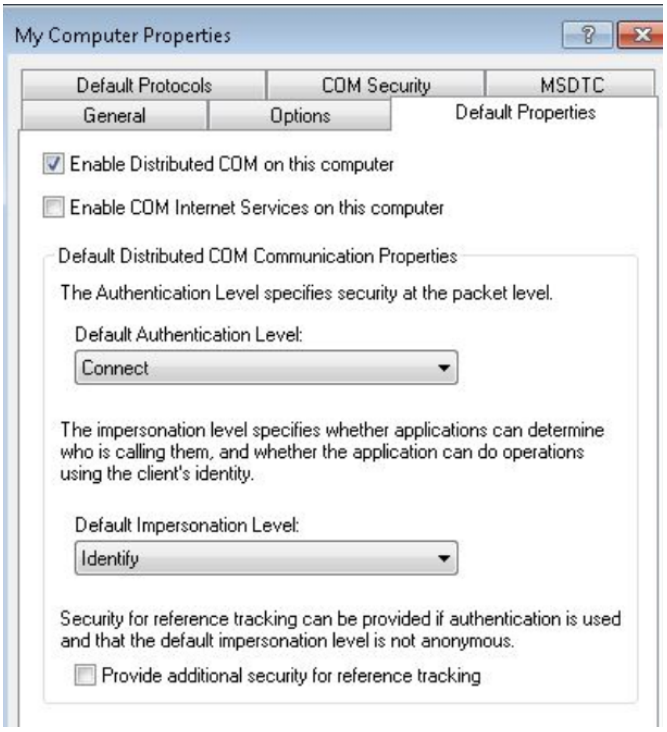


f. Reboot the system after these changes are made. Repeat the process on each client. This completes the OPC client-side configuration.

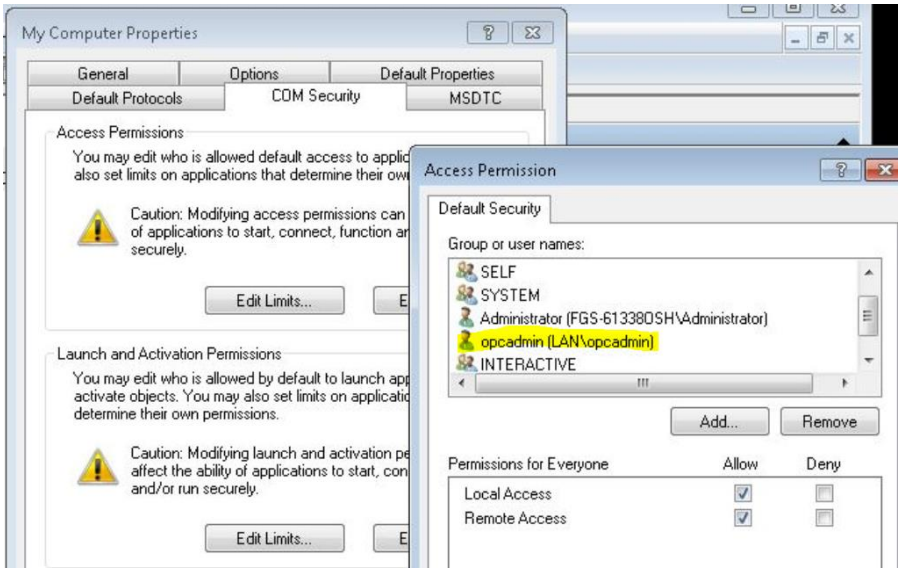
4. Make the following changes to the DCOM properties on the **OPC server system:**

a. Launch the **Control Panel** > **Administrative Tools** > **Component Services** snap-in to open the DCOM console.

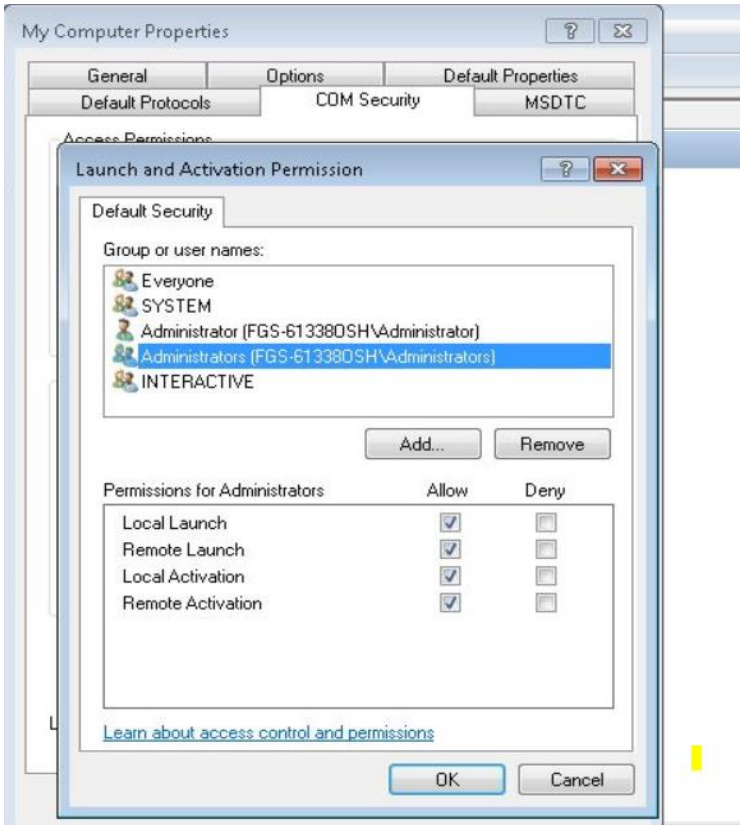
b. Expand **Console** Root > **Component Services** > **Computers**. Right-click **My Computer** > **Properties**. Ensure the settings are as follows



c. Click on the **COM Security** tab > **Access Permissions** > **Edit Default** > Add the **opcadmin** user and grant it ALLOW permissions for Local Access and Remote Access boxes.



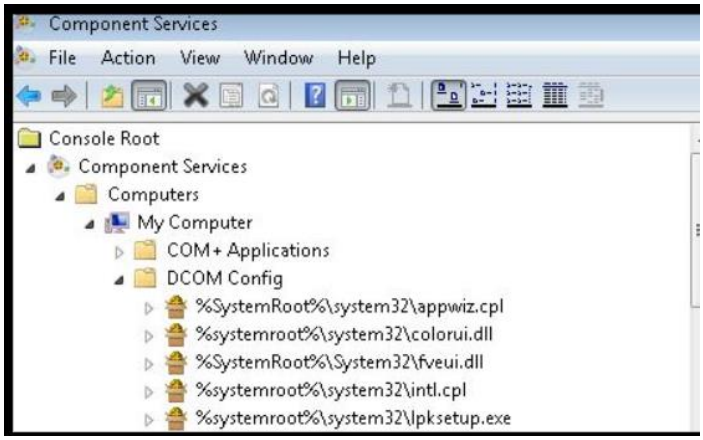
d. Click Edit Default under **Launch and Activation Permissions**> Add the Administrators group. Check on **ALLOW** Boxes for all 4 categories. If adding the other opcuser, it will only have Local Launch permissions.



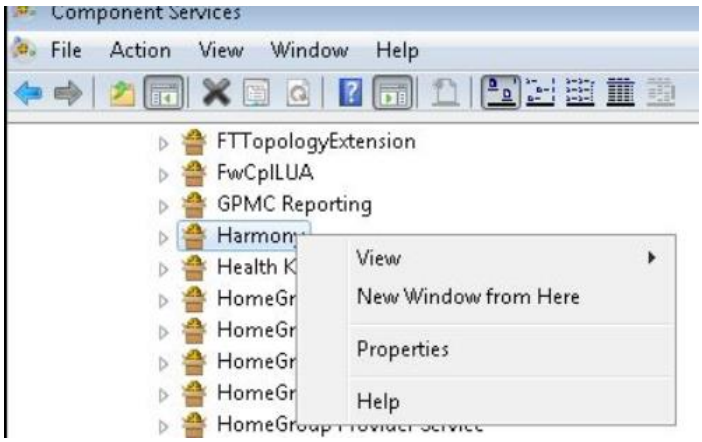
5. Note down the names of the opc-server software installed in your environment on the OPC make the DCOM changes as explained below on each of their application folders. In our case, the list of the s/w is as follows
   - Harmony (Installed on OPC Server)
   - RSLINX (Installed on OPC Server)
   - MATLAB (Installed on the Controller)

6. Make the following changes on the application folders of the OPC-server & Client system

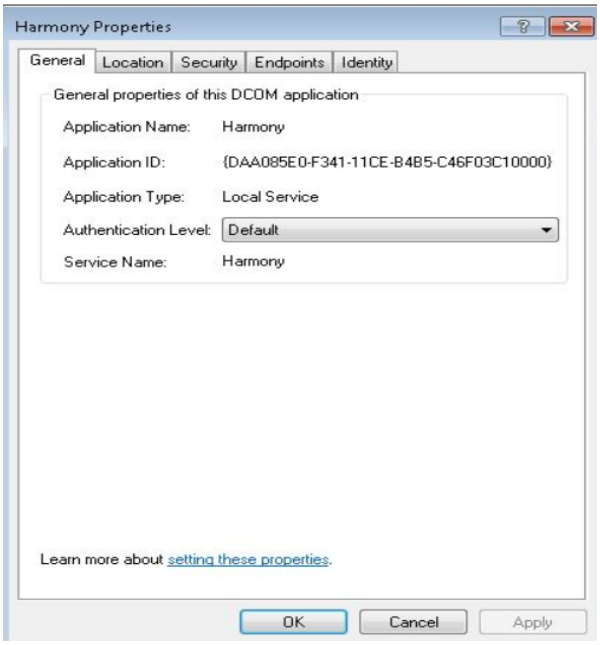
   a. Launch the DCOM console. Browse to **Console Root > Component Services > Computers > My Computer > DCOM Config**.



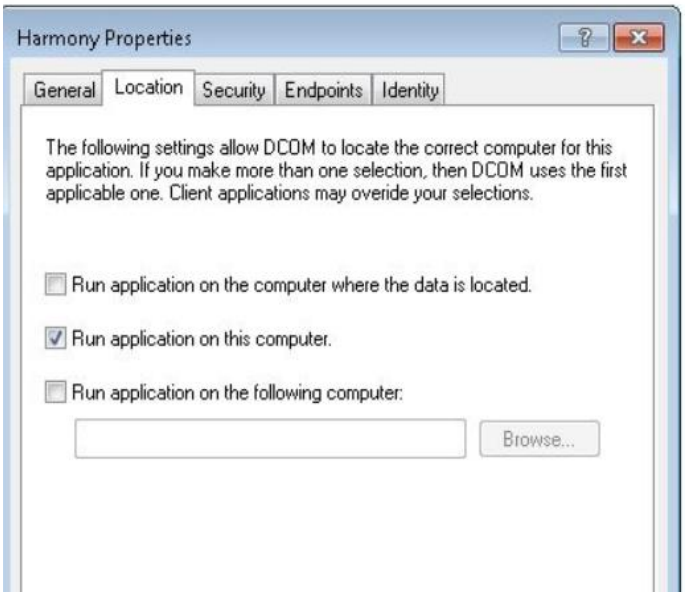
   b. Right-click the <application folder> from the list of applications in the right pane Click **Properties.** For example, find the "**Harmony**" folder, right click to view its Properties.



c. Set **Authentication Level** to **Default** on the **General** tab.



d. Select **Run application on this computer** on the **Location** tab.



e. Assign the following permissions to the **opcadmin** account on Security Tab:

- Launch and Activation Permissions: Use System Defaults
- Access Permissions: Use System Defaults
- Configuration Permissions: Customize Full Control as shown below. (Note opcadmin is a member of Administrators group)

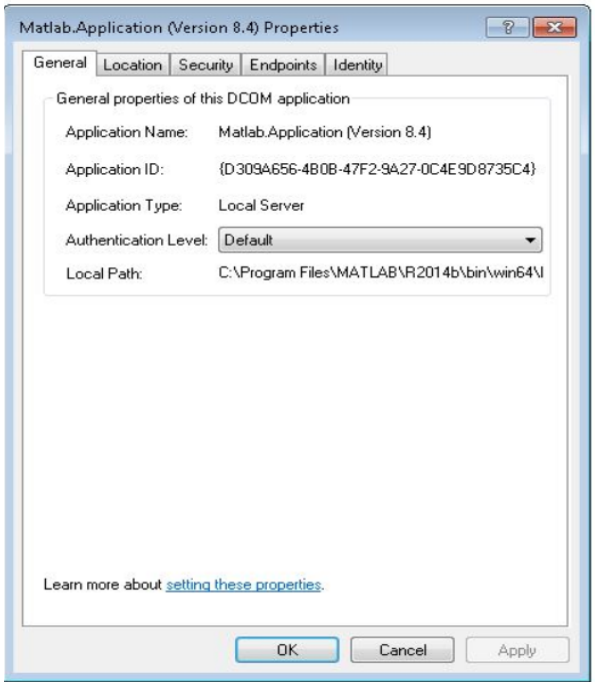
f. Assign the following permissions to the **opcuser** account on Security Tab:

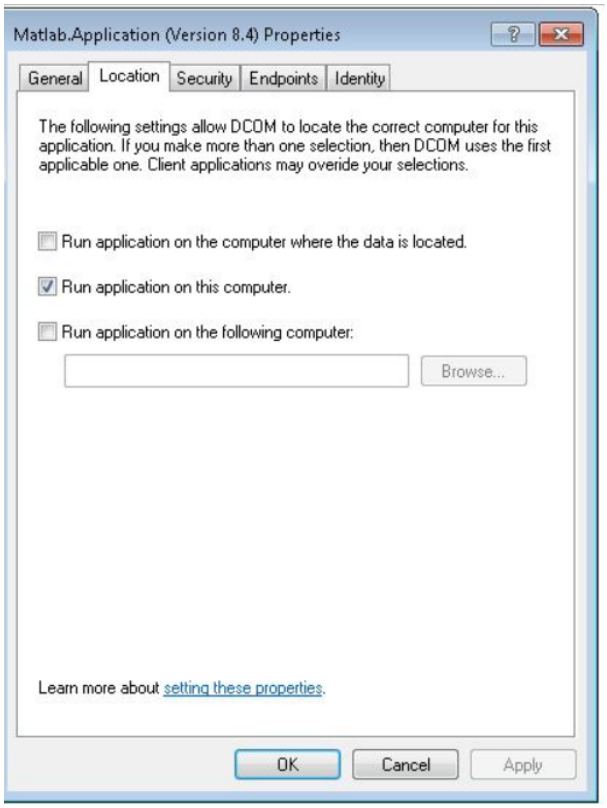
- Launch and Activation Permissions: Use System Defaults
- Access Permissions: Use System
- Configuration Permissions: Allow Read

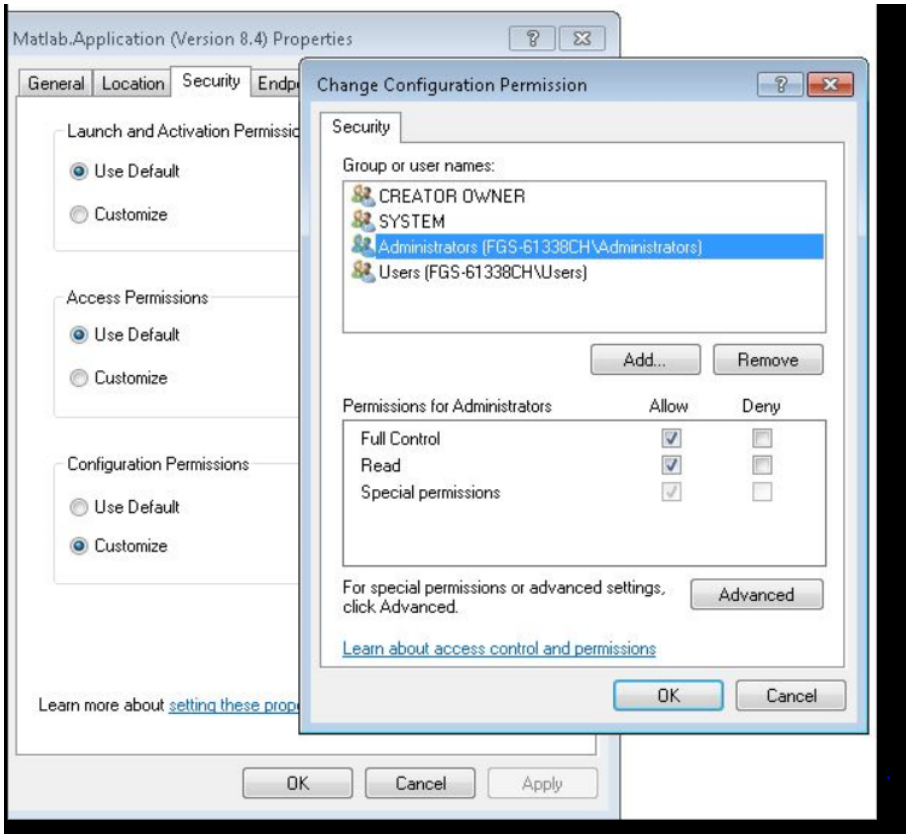
g. Choose the **This user** option under **Identity** Tab. Enter the user name and password for the admin user **opcadmin** AD account. Click **OK** to save your settings. Reboot system.

h. Repeat the above steps on the other application folders such as RSLINX and MATLAB (on the Controller Server in our case).
i. Reboot system when done.

Shown below are some screenshots of the MATLAB folder for reference.







4.9.5.5 Radius Server Setup

For authenticating VPN users & configuring AD based authentication for network devices, a Windows 2012 R2 server running Active Directory and Windows Network Policy Server (NPS) was setup in the Management LAN to authenticate the boundary firewall and VPN users. Technically both the roles can be on the same server but its recommended to keep them separate for redundancy.

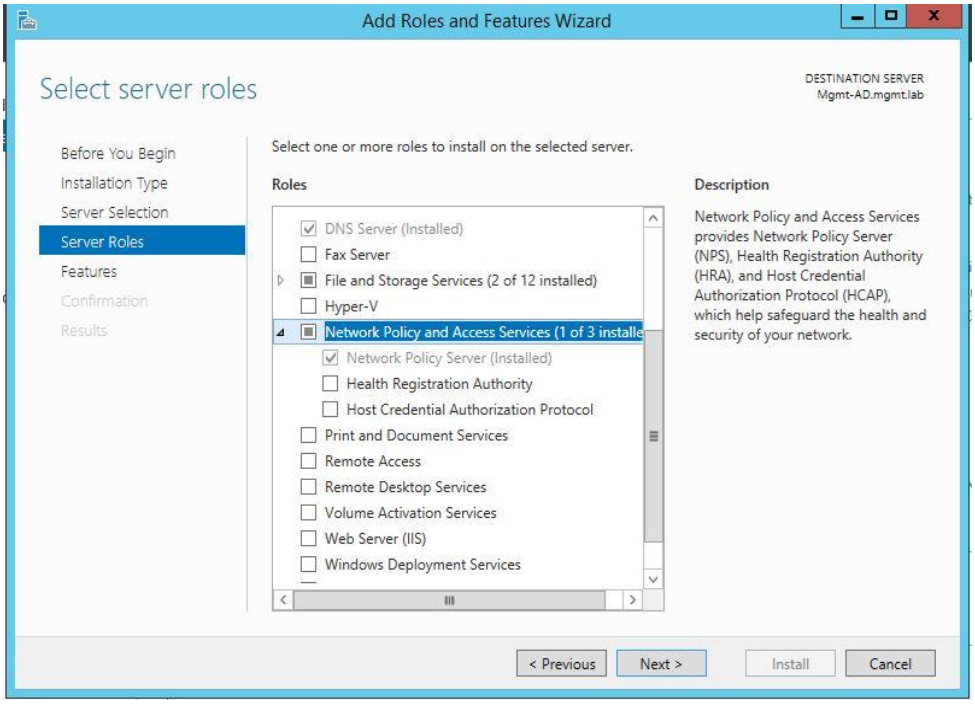
Details of the AD Server and Domain in the Management Network

Hostname	IP address	Roles	Domain Name
Mgmt-AD	10.100.2.3	Active Directory, DNS, Network Policy Server (Radius)	Mgmt.lab

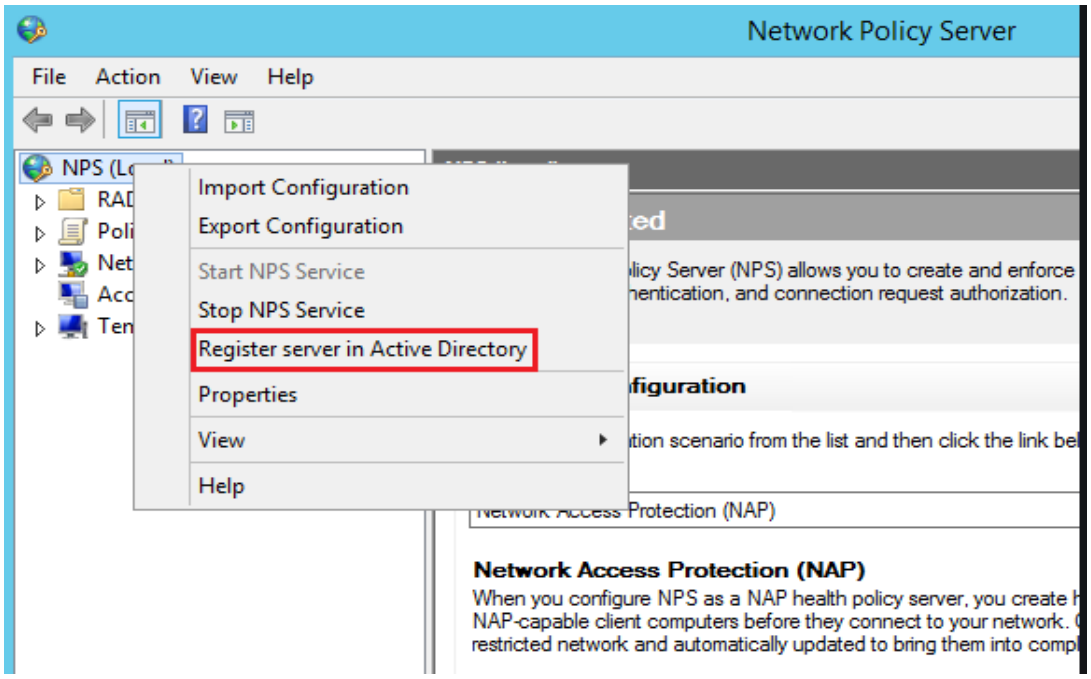
The High-level steps involved in this setup are:

- Setup the AD Server and create an AD Domain
- Setup user account & groups in AD for authenticating to network devices.
- Setup the Radius Server
- Register Radius Server with AD
- Create Radius clients and network policies

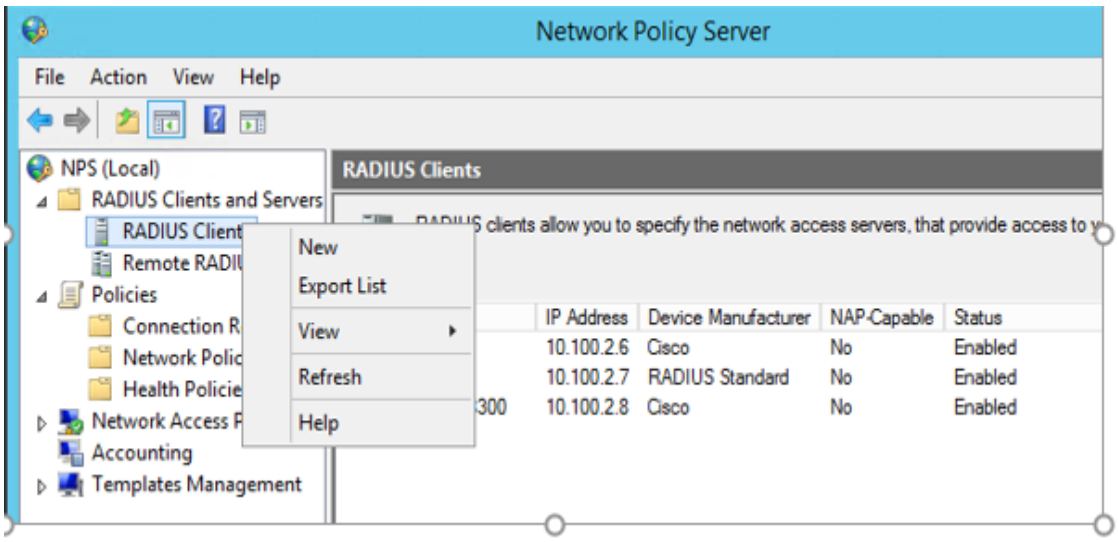
1. Follow the steps in the previous section to setup an AD server and creating a domain.
2. Create user account(s) in AD for logging in to the network devices. Once done, create security group(s) as required for regulating access for this user account.
   For instance, a user account called **icsuser01** and a Security Group **Network Admins** were created in our **mgmt.lab** domain. The **icsuser01** user was added to the Network Admins group.
3. Follow the steps below to setup a Radius server on a Windows 2012 R2 system
   a. Launch Server Manager. Click **Add Roles and Features**
   b. Install the **Network Policy Server** role.



c. Open the Network Policy Server Console. Right-click **NPS (local)** > Click on **Register Server in Active Directory**

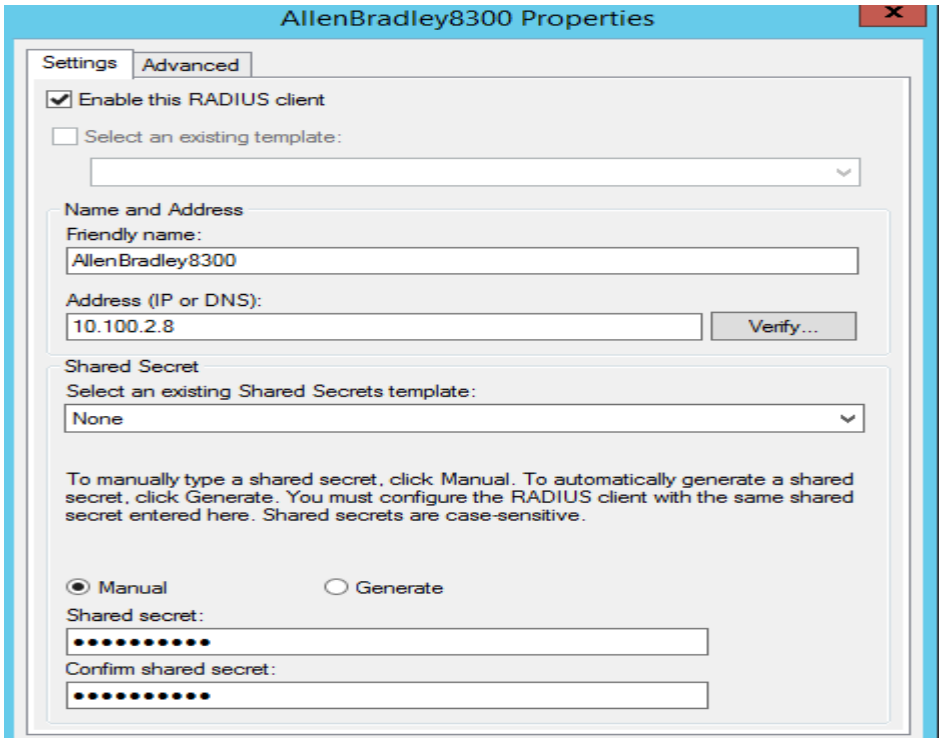


4. Create Radius Clients and Policies in NPS as follows:
   a. Launch the **Network Policy Server** snap-in, Right-click **Radius Client** > **New** to create a Radius client for the Network Device in question.

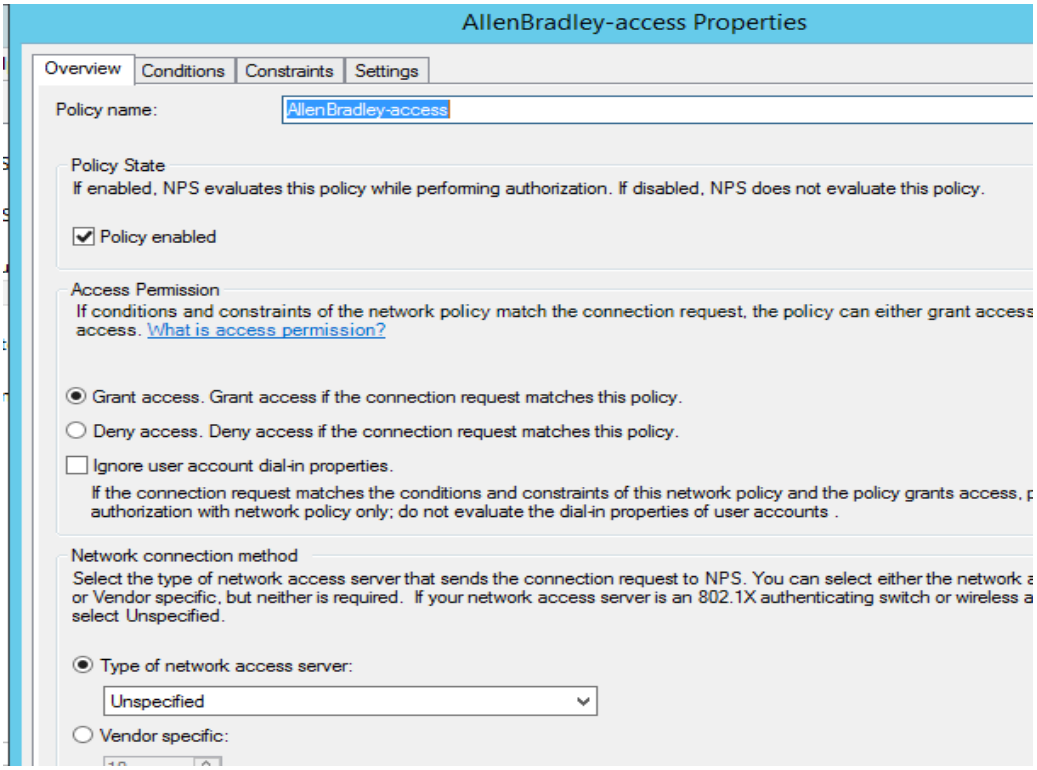


   b. Enter a matching name of the Network Device, IP address of the management interface of this device and create a strong passphrase. Hit **OK** when done. This will create the Radius client. Verify that you can ping the IP address of the network device from the Radius server.

The image below shows a Radius client created for the Allen Bradley Boundary Router/Firewall device in the plant.

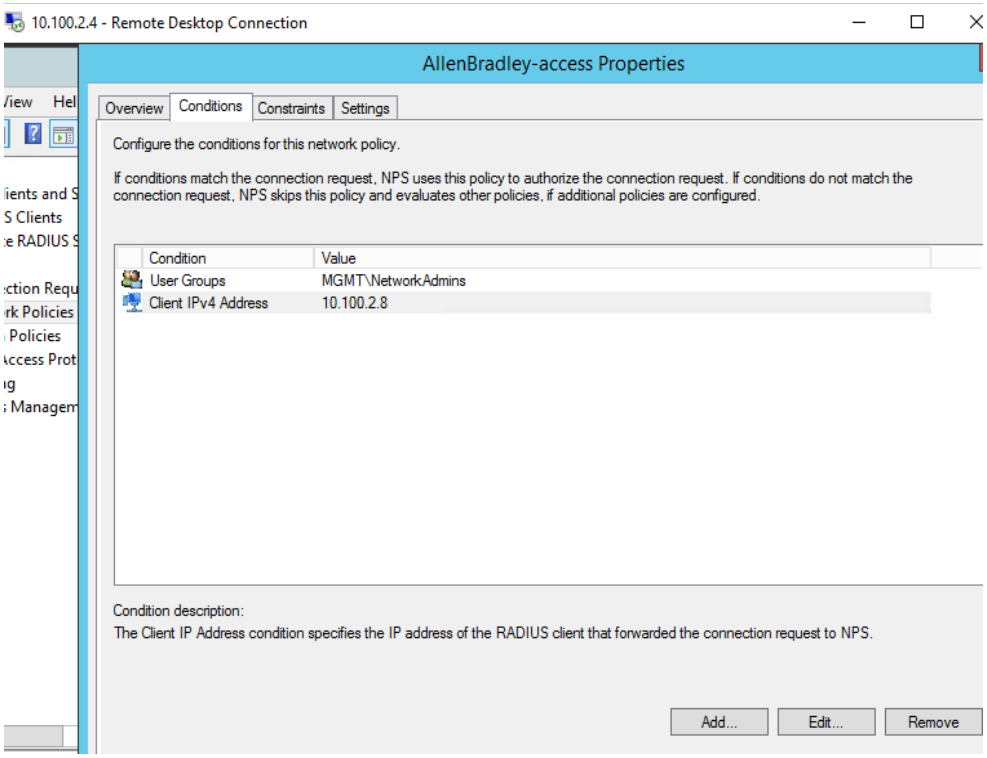


c. Create a new policy for the radius client by clicking on **Policies** > **Network Policies**. The image below shows the network policy created for the Allen Bradley firewall

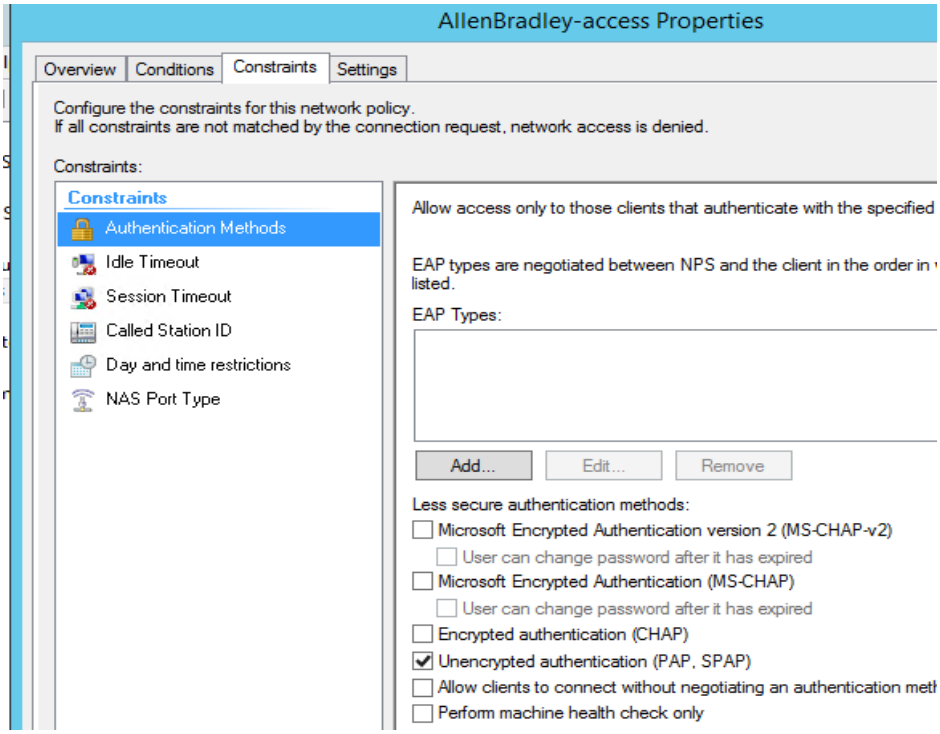


d. Click on **Conditions** tab to define Conditions for the policy.
e. Click **ADD** button > Select the **user/groups** option from the list > Select the security group (Network-admins) setup earlier in our AD. This will allow users from this group to login as admins for managing the switch.

f. Add another condition to check for the IP address of the Radius client. Select **Client IPv4 address** option from the list. Enter the IP address of the network device and add it. Please refer to the image below for a completed Conditions page once both conditions are added. Hit **Next** to proceed to the next screen.

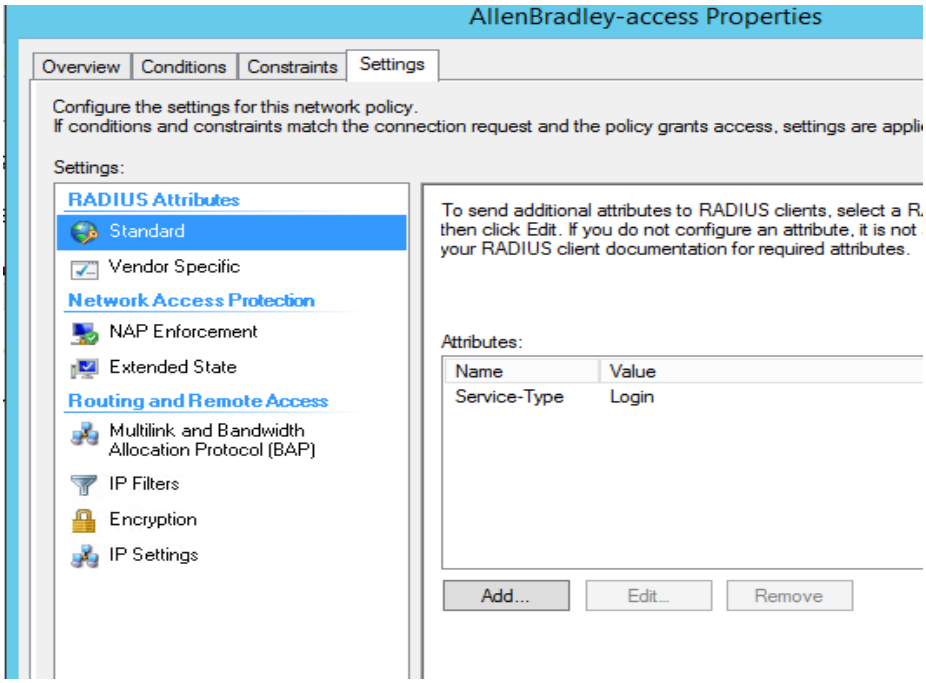


g. Select **PAP, SPAP** authentication method as recommended by Cisco. Click **Next** to proceed to the Settings page.

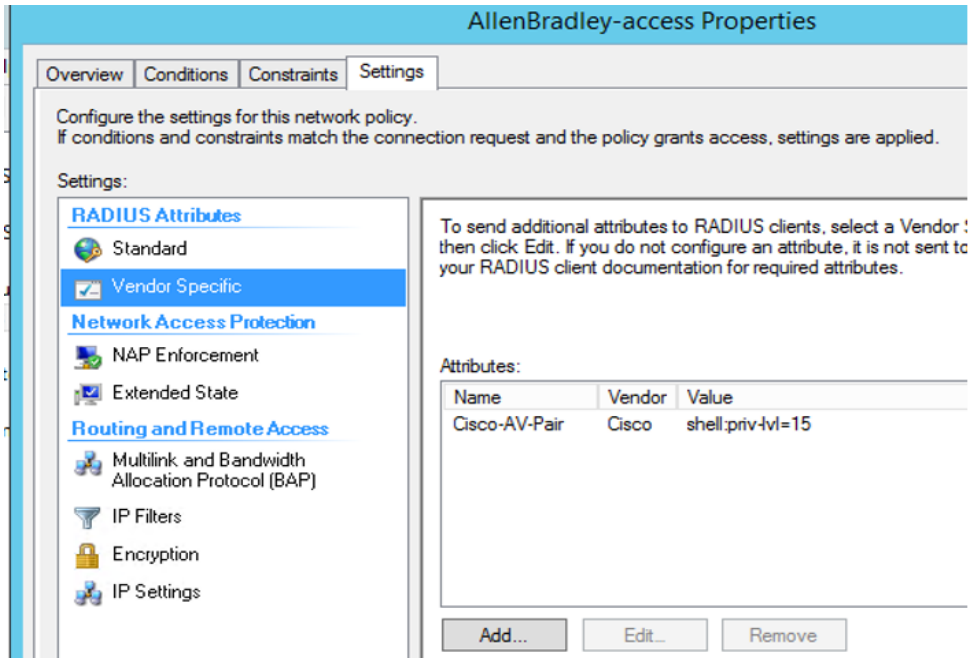


h. Click **Standard** > under **Radius Attributes** in the Settings page.

i. Remove the 2 default attributes. Click **ADD** to add a new attribute with **Name = "Service-Type**" and **Value = "Login"** as shown below.



j. Add a new attribute under **Vendor Specific Attributes** by selecting **Cisco-AV-pair** from the list,
Vendor = Cisco
Value = shell:priv-lvl=15
This will assign the user **privilege level =15** meaning root level privileges.
k. Click on **OK/Apply** button to save the changes



4.9.5.6 Configuring Boundary Router for Radius Authentication

1. Configure AAA group on the Boundary Router for authenticating against a Radius server.

   The following commands were run on our Allen Bradley Boundary firewall to enable it to authenticate against the Radius server.

```
#enable
#configure terminal
(config)#aaa new-model
(config)#aaa authentication login default group radius local
(config)#aaa authorization exec default group radius local
(config)#radius server host 10.100.2.3
(config)# radius server-key <passphrase>
(config)# end
#wr mem
```

4.9.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Active Directory service while the manufacturing system was operational:

PL002.1 Active Directory service active with non-OPC accounts being configured as non-Administrator privilege.

There was no performance impact to the manufacturing process observed during the experiment. However, performance impact was observed at the implementation of the Active Directory (AD) service. At the initial implementation, the team focused on the Active Directory installation and user configuration, but not knowing the need for DCOM configuration initially, causing unplanned production interruption. DCOM and user account configuration for every OPC client were modified to use AD instead of local authentication. Without modification, the OPC client failed to communicate with the OPC DA server and caused all OPC data exchange to cease operation. This failure caused the manufacturing process entered the emergency shutdown state.

Another impact observed at implementation was the time synchronization source with the AD. Authentication failed due to time discrepancy between hosts and AD. It is because the hosts were synchronized to a different time source than the AD and the time difference was greater than 5 minutes. When the host joins the AD domain, each host should use the same time source as AD. For example, all hosts in PCS use AD as the time source, and AD uses an external NTP server as its time source.

Care should be taken to ensure proper operation of the Active Directory service. Failure in authentication causes error in operation of the OPC server, which handles all the data exchange of the controller and the plant operation. The manufacturing process entered emergency shutdown state because the controller lost the ability to communicate to the sensors and actuators. Redundancy and backup are highly recommended. Ability to switch between primary and secondary AD should be seamless to avoid impact to the system.

There was no significant impact to the network performance observed. For example, the round trip time from OPC to HMI is mostly the same with the Active Directory.

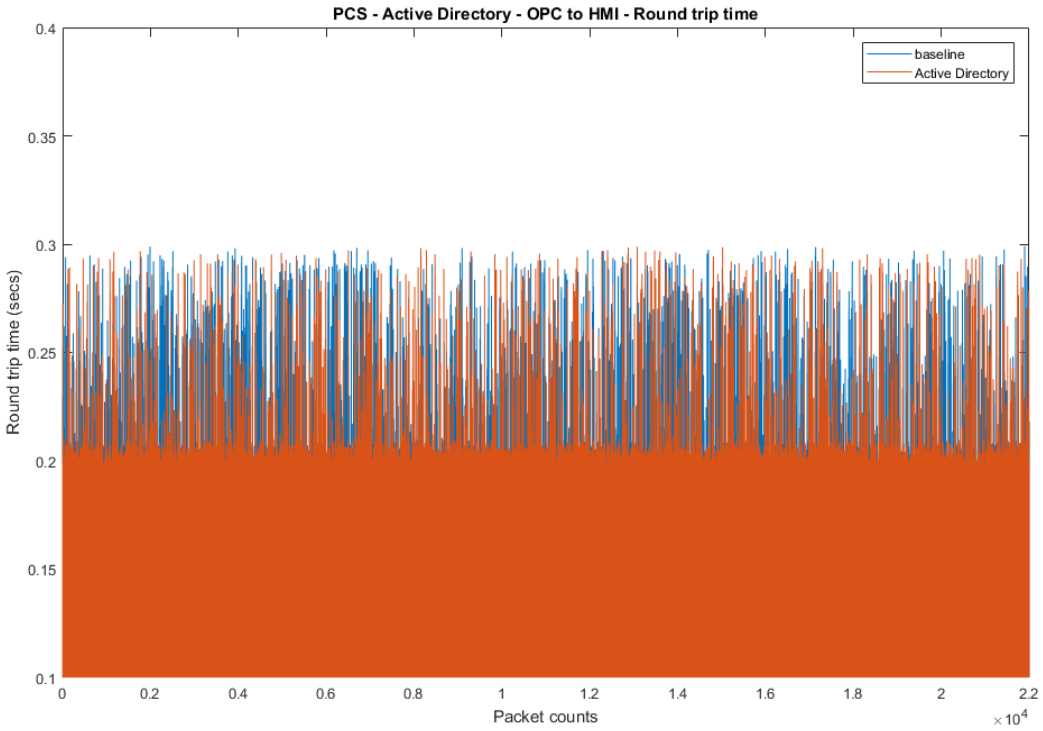


Figure 4-16 Packet round trip time from OPC to HMI with Active Directory.

The controller is another major component required modification to use Active Directory. The Controller authenticates against the AD server. The controller also has the updated DCOM so that it can continue to communicate with the OPC server. The packet round trip time from the Controller to OPC was slightly elevated, with a small number of packets had a slightly increased round trip time. There was no significant increase in inter packet delay from the Controller to OPC observed.

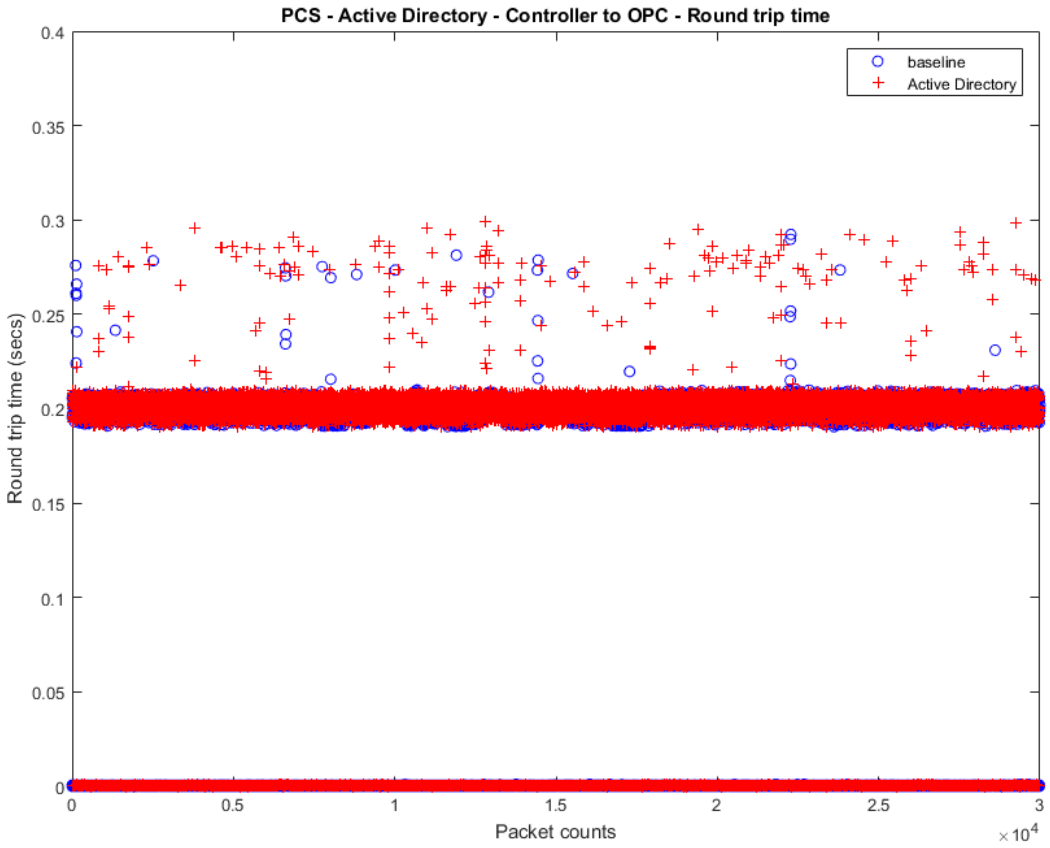


Figure 4-17 Packet round trip time from Controller to OPC with the Active Directory enabled (red)

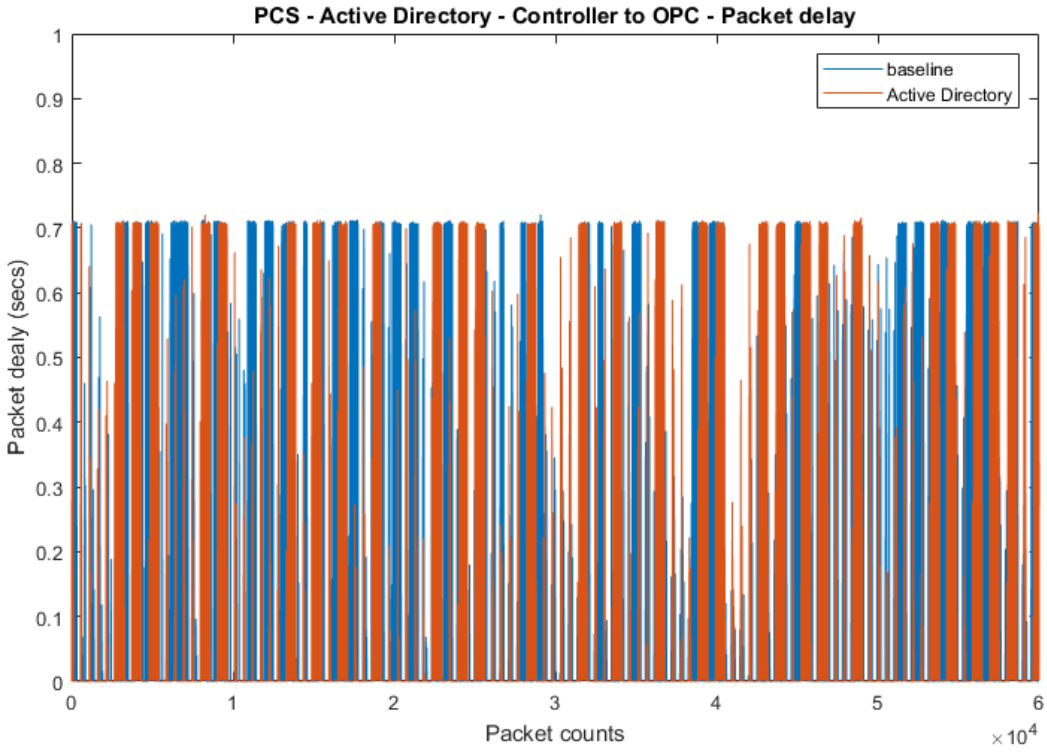


Figure 4-18 Inter packet delay of Controller to OPC with the Active Directory enabled (red)

There was no significant performance impact to the manufacturing process observed with the use of Active Directory. For example, the product flow rate remained consistent with and without the use of Active Directory.

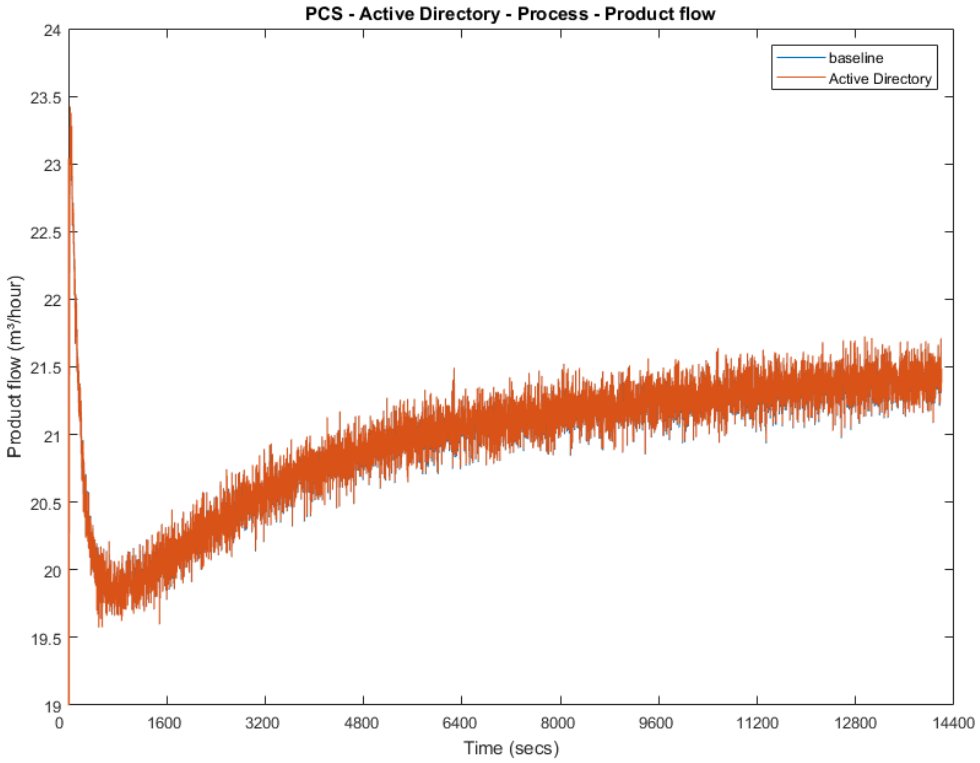


Figure 4-19 Manufacturing process product flow rate during the use of Active Directory (red)

A misconfiguration on the Active Directory caused the manufacturing process to enter the emergency shutdown state in about 600 seconds of the experiment time due to the reactor pressure too high

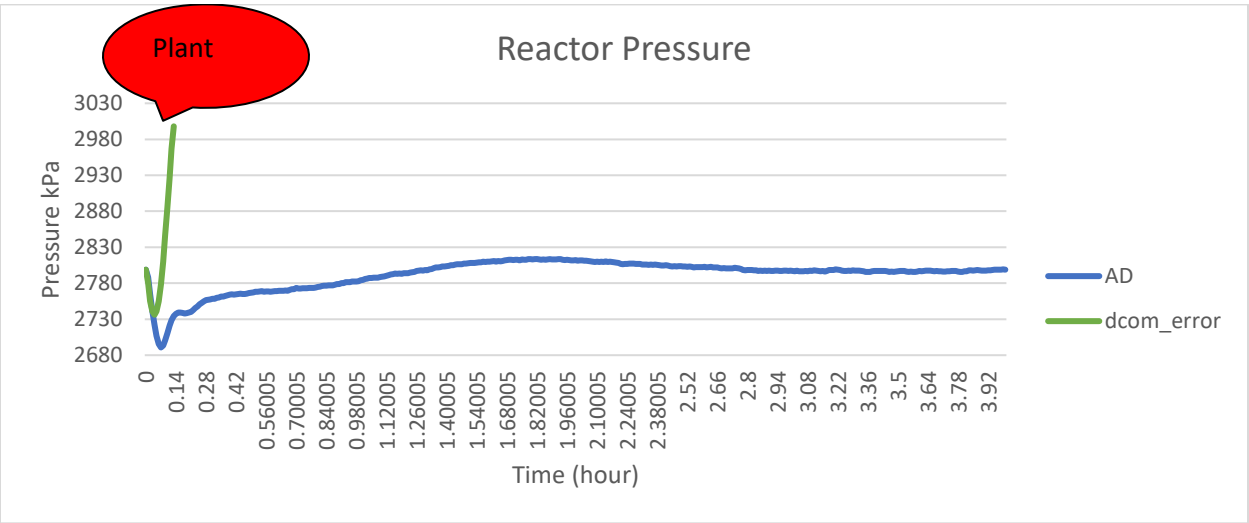


Figure 4-20 Plot of the manufacturing process reactor pressure. The process entered emergency shutdown mode when DCOM communication failed.

4.9.7 Links to Entire Performance Measurement Data Set

- **Active Directory KPI data**
- **Active Directory measurement data**

4.10 Symantec Endpoint Protection

4.10.1 Technical Solution Overview

Symantec Endpoint Protection (SEP)[88] is an endpoint protection solution that can help defend against ransomware and other emerging threats.

Points to consider:

- Next Generation Antivirus / Endpoint protection solution to prevent against virus attacks and emerging cyber threats such as zero-day attacks, ransomware etc.
- OS Platform independent: The endpoint agents are supported on Windows and Linux.
- Comes with a lightweight agent and virus definition sets that require minimal network bandwidth.
- Diverse Feature set: Core capabilities include Antivirus, Host Firewall, Intrusion Prevention, Host Integrity, System lockdown, Application White listing and USB Device Control.
- Centralized Management: All endpoints, rule sets, policies can be centrally managed from the Symantec Endpoint Manager console.
- The Symantec Manager component is supported only on Windows OS.
- The Linux agent requires the OS kernel on Linux systems to be at a certain level for installation. In addition, the Linux agent is a 32-bit installer. If installing on a 64-bit Linux system, it requires certain 32-bit packages/libraries to be installed as a prerequisite. This may conflict with some of the existing packages on the system.
- The endpoint agent on each system by default needs to communicate outbound with a range of public IP addresses for its Reputation analysis and Global Threat intelligence feature. It is recommended to allow this traffic from your firewall to leverage the advanced features of the product.
- **Important**: System reboot is required to complete the installation process on clients/endpoints.

4.10.2 Technical Capabilities Provided by Solution

Symantec Endpoint Protection provides components of the following Technical Capabilities described in Section 6 of Volume 1:

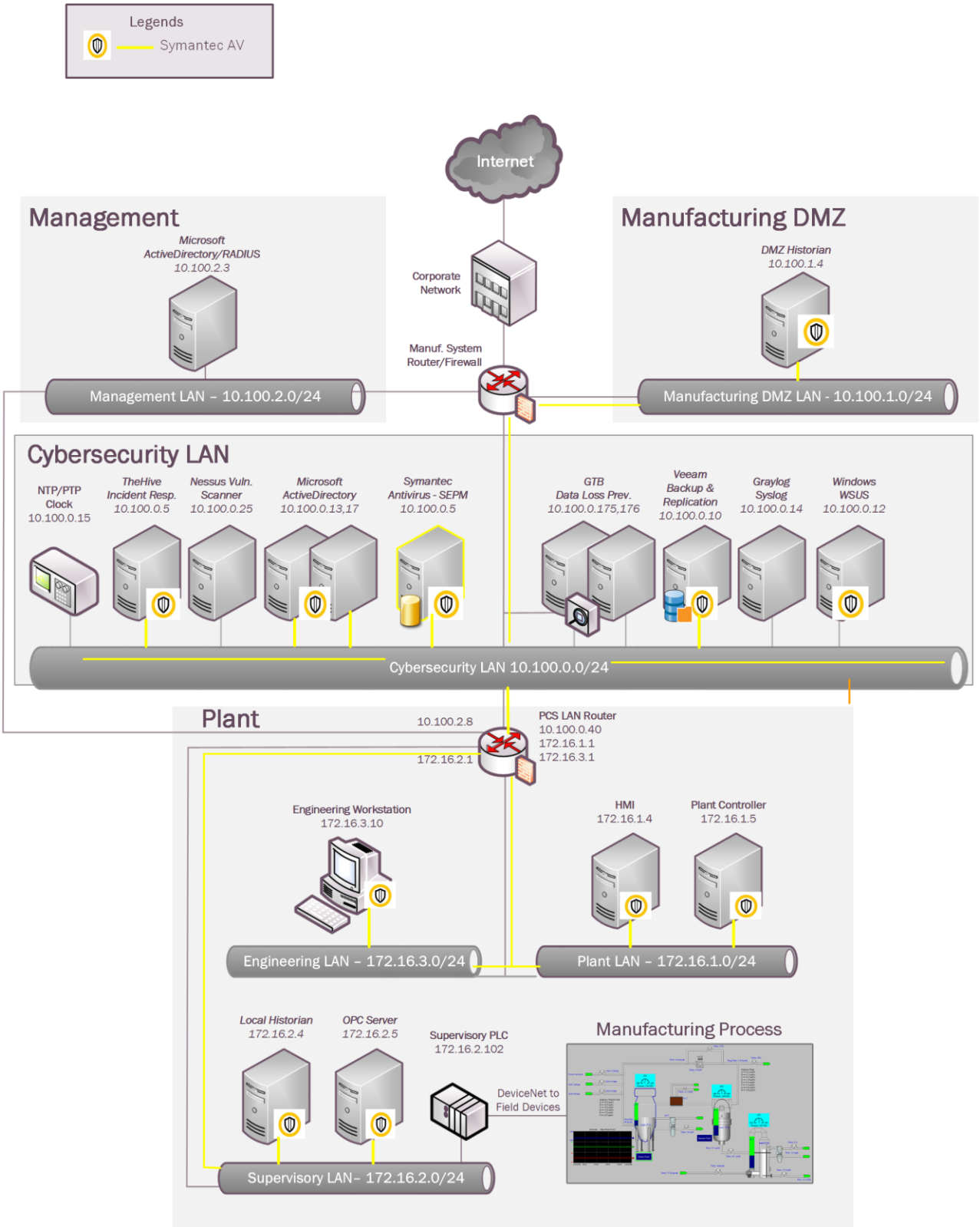
- Anti-virus/malware

4.10.3 Subcategories Addressed by Implementing Solution

DE.CM-4

[88] https://www.symantec.com/content/dam/symantec/docs/data-sheets/endpoint-protection-14-en.pdf

4.10.4 Architecture Map of Where Solution was Implemented



4.10.5 Installation Instructions and Configurations

Details of the solutions implemented:

Name	Version	Deployment mode	Hardware Details
Symantec Endpoint Protection Manager (SEPM)	14.2 Build 758	On-premise	Hyper-V Virtual Machine (Generation 2): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 70 GB • Network: 1 network adapter • OS: Windows 2012 R2
Symantec Endpoint agent for Windows (Client)	14.2.758.0000		Installed on all Windows systems of the plant

4.10.5.1 Environment setup

1. A virtual machine running Windows 2012 R2 was setup on a Hyper-V host server of the Cybersecurity LAN network of the plant with hardware specifications as described in the table above.
2. The guest OS IP information of this server was set as follows:

```
IP address: 10.100.0.5
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

3. The Symantec Endpoint Protection Manager (SEPM) virtual machine was deployed in the Cybersecurity LAN network of the plant. This central instance communicates with all the endpoint agents deployed on to the Process Control systems. Likewise, all endpoints report their status to the Manager server. The communication ports required to be opened are different for Windows clients as compared to Mac/Linux clients. A detailed list of firewall ports[89] is available for reference.

4.10.5.2 Setup of the SEPM Server

1. Download the Symantec Endpoint Protection .zip bundle from the Symantec website. A license is required to register and download the product.
2. Open the extracted folder and run the **Setup.exe** file. Mid-way during the install, enter a strong admin password when prompted.

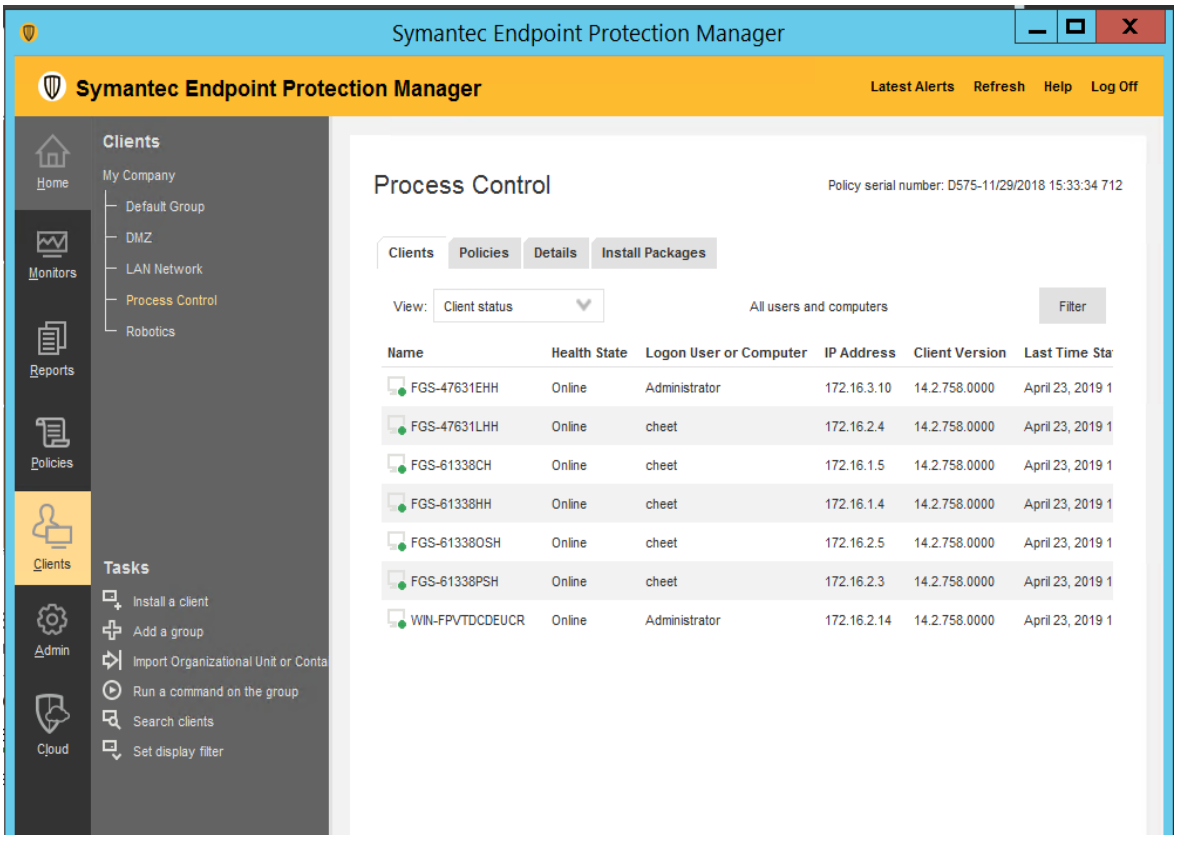
[89] https://support.symantec.com/en_US/article.HOWTO81103.html

3. Select the **Backed Database** selection page on the Database selection page. Choose the **Embedded database** if you do not have a MS SQL Server. Follow the on-screen instructions and complete the installation wizard.
4. **Reboot** the server once done.
5. Launch the Symantec Endpoint Protection Manager (SEPM) console and login with the admin user created earlier.
6. Activate the license key to begin using the product.

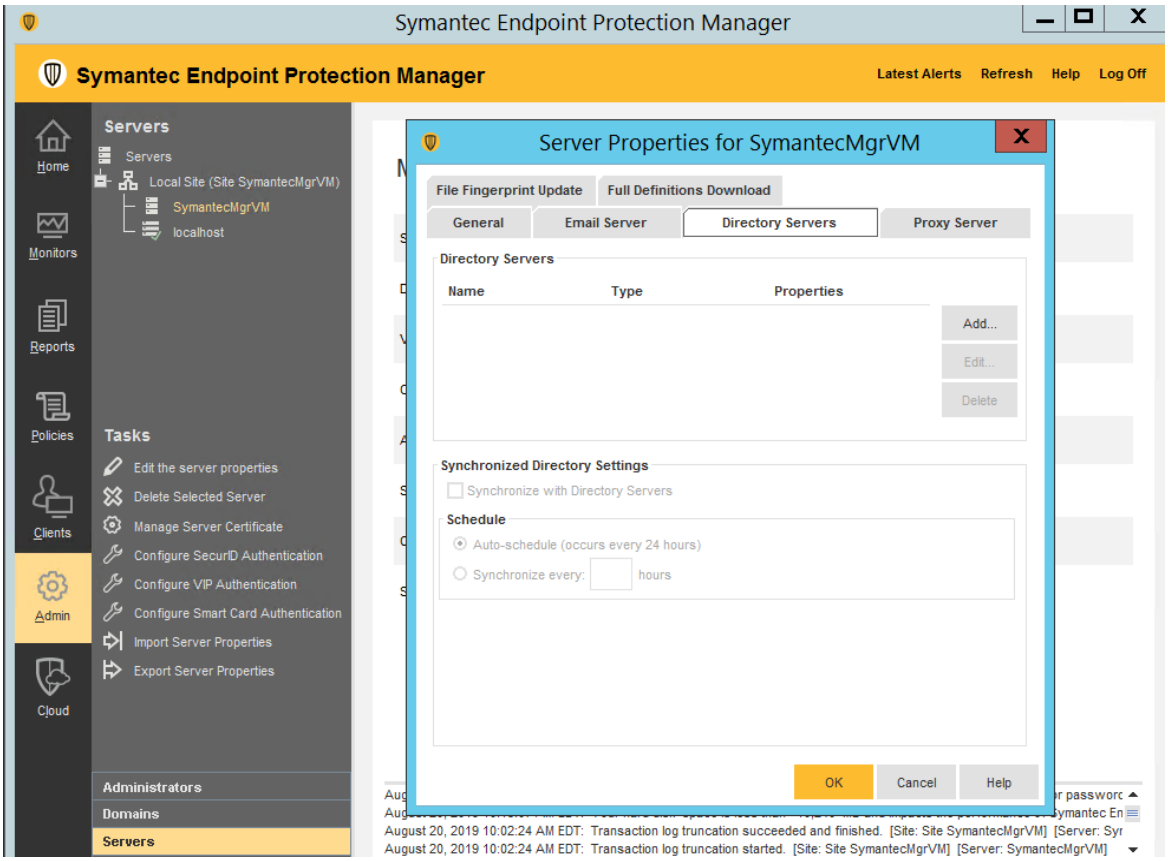
4.10.5.3 Configuration of the SEPM server

1. Configure Client groups to group devices as follows
   a. Click on **Clients** option from left-side menu
   b. Click on **Add a group**
   c. Enter a **Name**

   For instance, the image below shows the different client groups created in our network to group devices from each of the systems.

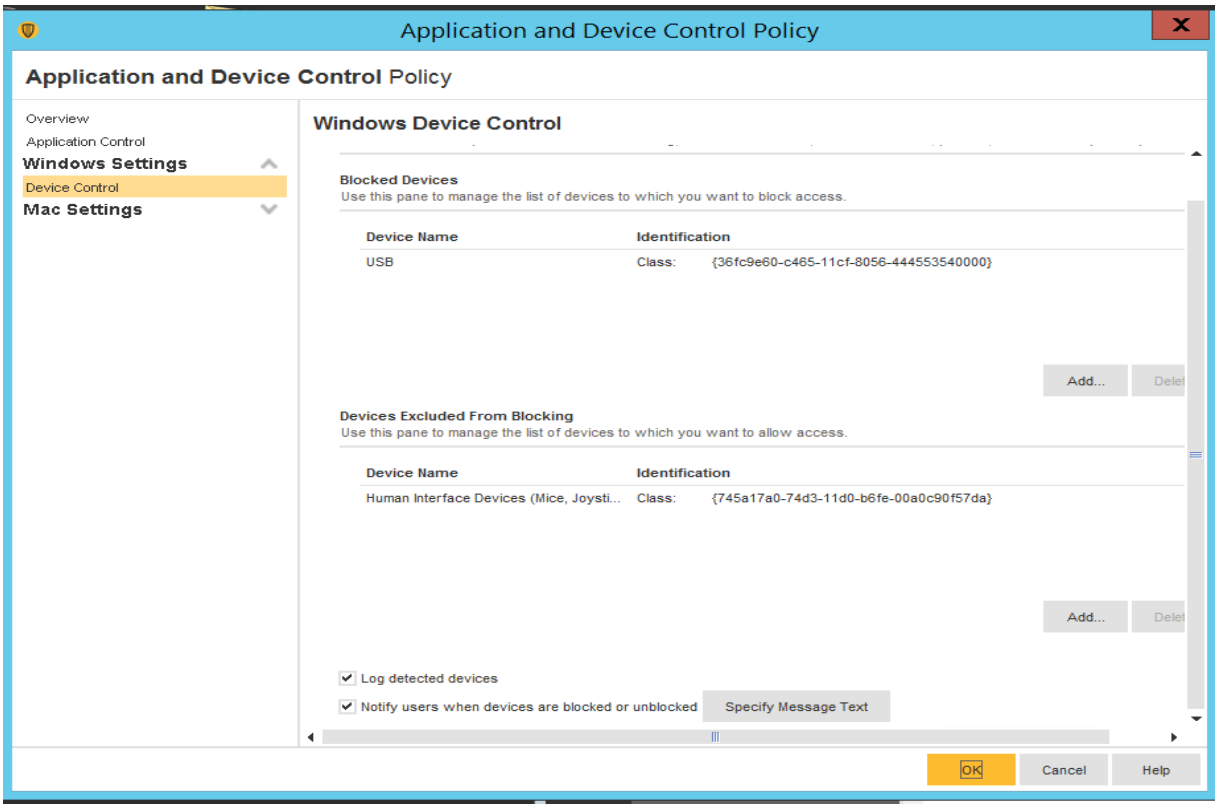


2. Integrate SEP Manager with Active Directory/LDAP using the following instructions
    a. Click on **ADMIN** > **Servers** > **Local Site** > ***Server Name*** > **Edit Server Properties**
    b. Click on **Directory servers** tab under **Server Properties for <*Server*>.**
    c. Click further on **ADD** button as shown below to configure domain details.
    d. Logout once done and try logging in back with your AD credentials.



3. Configure SMTP server using the following instructions,
    a. Click on **ADMIN** > **Servers** > **Local Site** > ***Server Name*** > **Edit Server Properties**
    b. Click on **Email server** tab under **Server Properties for <*Server*>.**
    c. Enter the details. Click OK when done.
4. Configure a policy for **Excluded Hosts** to **exclude** IP addresses of systems such as vulnerability scanners from getting blocked when performing a scan.
    a. Click **Policies > Intrusion Prevention or Create a new Policy**
    b. **Click Excluded Hosts**. Add the IP address of the system in question.
    c. **Link** the policy to the appropriate client group.

5. (Optional) Setup device control such as restricting USB devices using the following instructions.
   a. Create a policy under **Application and Device Control**.
   b. Click Device Control
   c. Click Add under Blocked devices
   d. Select one or more devices to block. For instance: USB
   e. Ensure to select Keyboard and Mice under **Devices excluded from blocking**.[90]



[90] https://support.symantec.com/us/en/article.howto80866.html

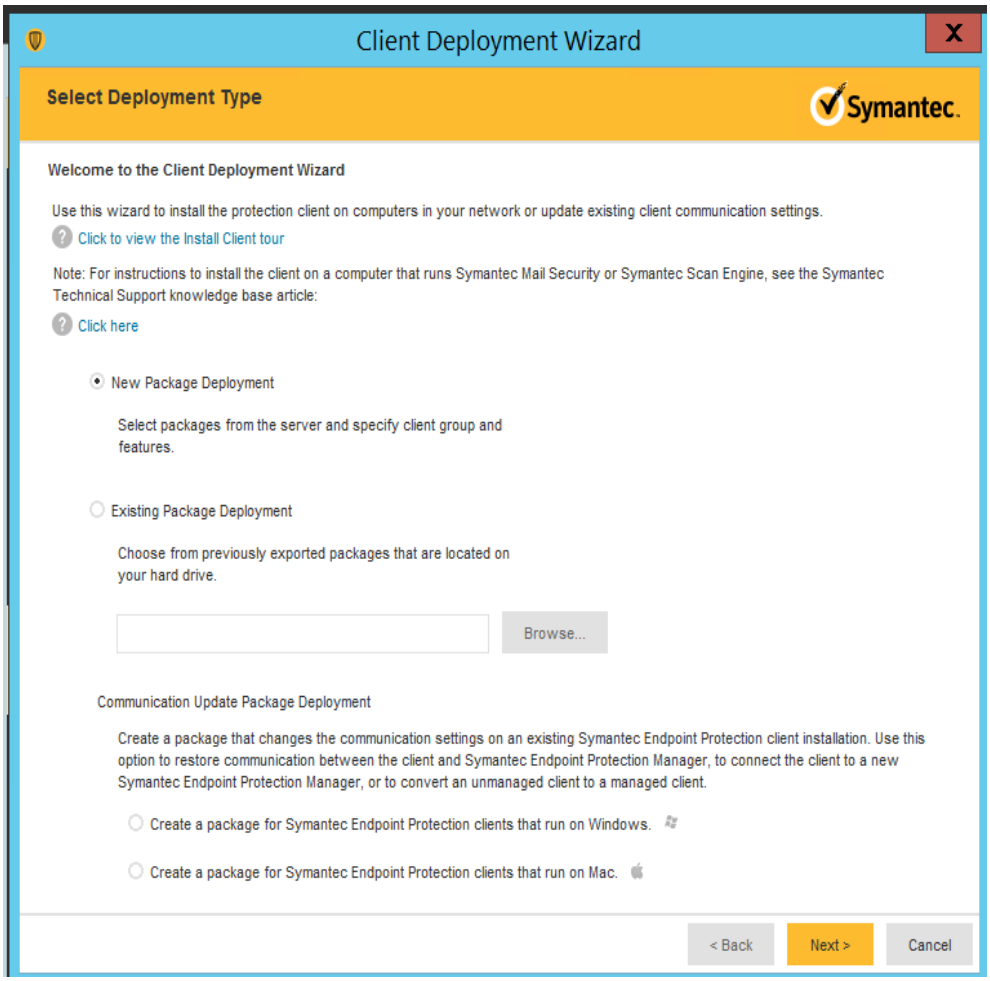
4.10.5.4 Installing Endpoint Agent on Client Systems

The high-level steps in getting the AV installed on client systems are as follows:

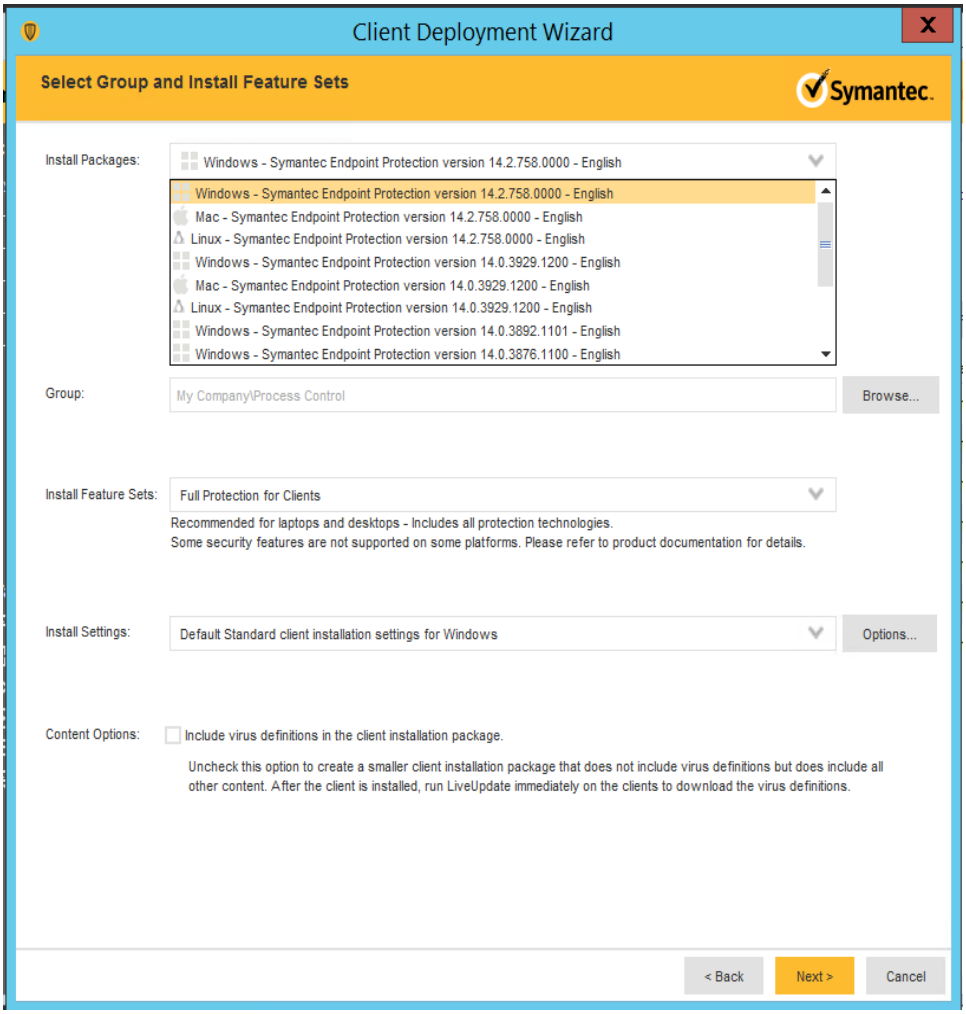
- Create a deployment package specific for a client group
- Deploy the package.
- Restart the client system to complete the install.

1. Creating a deployment package:

    a. Login to the Symantec Manager console. Click on **Clients** > ***Group Name*** where the endpoint device needs to be in.
    b. Click on **Install client** under **Tasks**. For instance, to create a deployment package for the group **Process Control**, click on that group name followed by **Install Client** option.
    c. Select **New Package Deployment** if this is your first agent installation of that group. If you have already deployed the agent on other systems of this group, you can re-use the same package and skip this wizard completely.



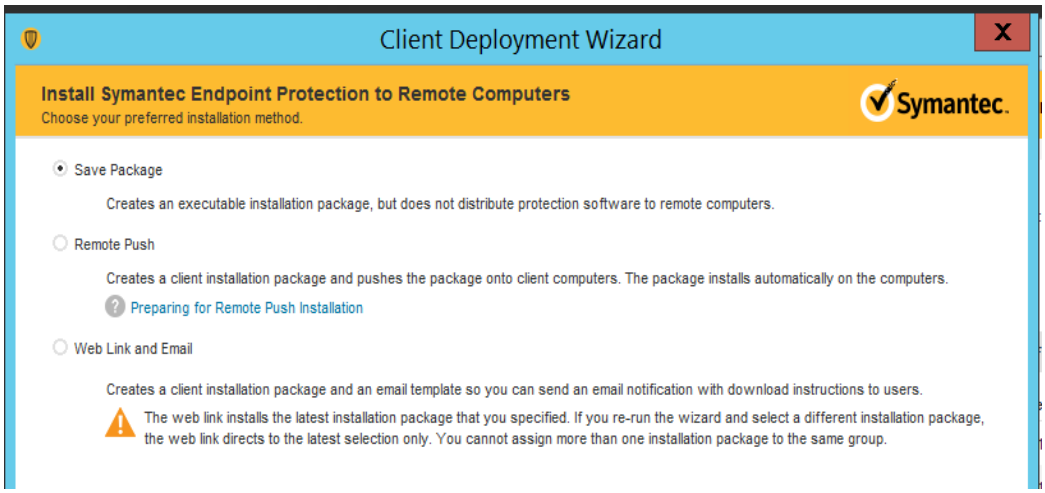
d. Click **Next**. Choose the appropriate OS Platform as per the endpoint OS, from the dropdown list of Install Packages. You will notice the Group Name is already prepopulated. This ensure the client will be placed directly in that group upon install.
e. (Optional) Select **Include virus definitions in the client installation package** under Content Options. Click **Next**.



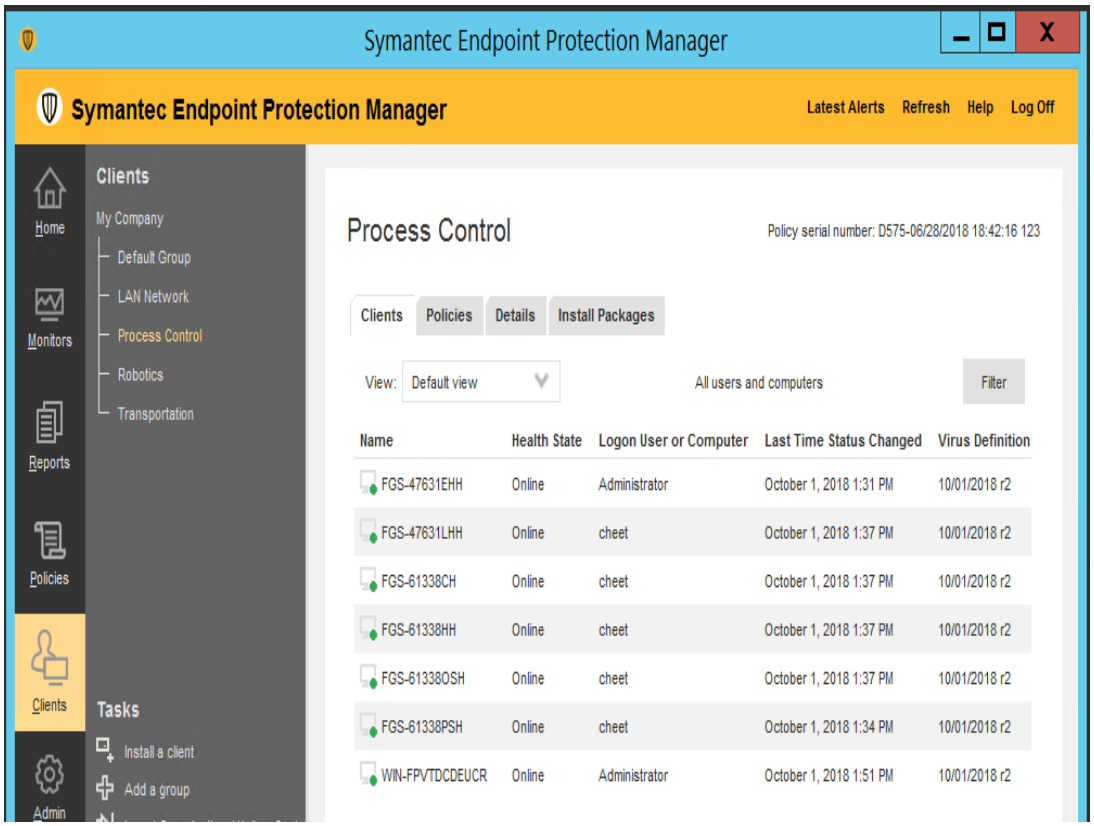
2. Deploying the package:

a. Select a preferred option of Installation method on the next page.
b. (Option 1) Choose **Save Package** to create a local installer which then needs to be copied over the target machine.
c. (Option 2) Choose the **Remote Push** method will make the SEPM server perform a network deployment to the target machine(s). Ensure the user has administrative privileges to install the package on the target system.

d. (Option 3) Choose **Web Link and Email** to email a link of the installer to the user.
e. Click **Next**.



3. Restart the endpoint machine upon installing the agent to complete the install process. Check the Symantec Manager console to verify if the client name is **green** ONLINE and the virus definitions are current.



4.10.5.5 Additional Information

- Official Symantec Endpoint Protection v14 installation guides[91]
- How-to-guides from Symantec for Endpoint protection[92] can be found at
- Official install guide for Windows systems[93]

Lessons learned

If using Symantec Firewall, ensure to disable the client's OS firewall to avoid conflicts. When you install the console for the first time, it adds a default Firewall policy to each group automatically. Similarly, a client typically gets default firewall settings if a firewall policy is not configured from the console.

4.10.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Symantec anti-virus tool while the manufacturing system was operational:

Experiment PL008.2- Symantec AV scan

During the Symantec anti-virus scan, sizeable performance impact was observed on the host processor Utilization. However, no significant performance impact was observed on the manufacturing process. A full Symantec scan can take up a considerable amount of processor power.

[91] https://support.symantec.com/en_US/article.DOC9449.html
[92] https://support.symantec.com/us/en/how-to-guides.html
[93] https://support.symantec.com/en_US/article.DOC9445.html

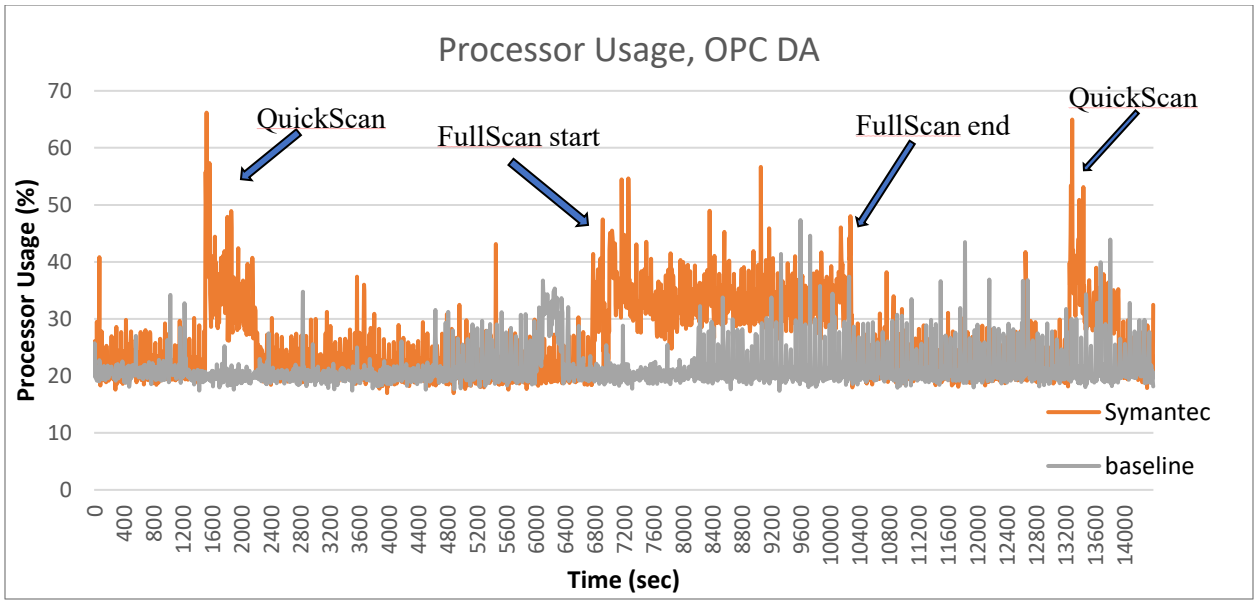


Figure 4-21 Plot of processor utilization of the OPC computer during the Symantec anti-virus scan (Red), and the baseline processor utilization (gray)

No significant performance impact to the network was observed. For example, the packet round trip time between the OPC and PLC remained mostly the same.

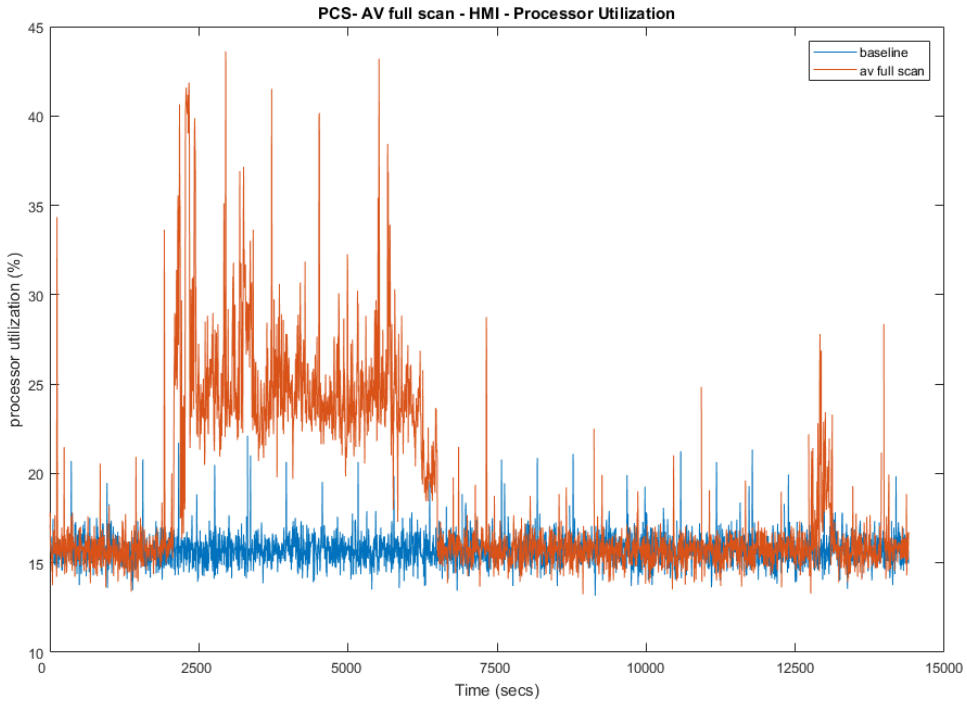


Figure 4-22 Plot of processor utilization of HMI computer during a Symantec scan (red) and without a Symantec scan (blue)

No significant performance impact to the network was observed. For example, the packet round trip time between the OPC and PLC remained mostly the same.

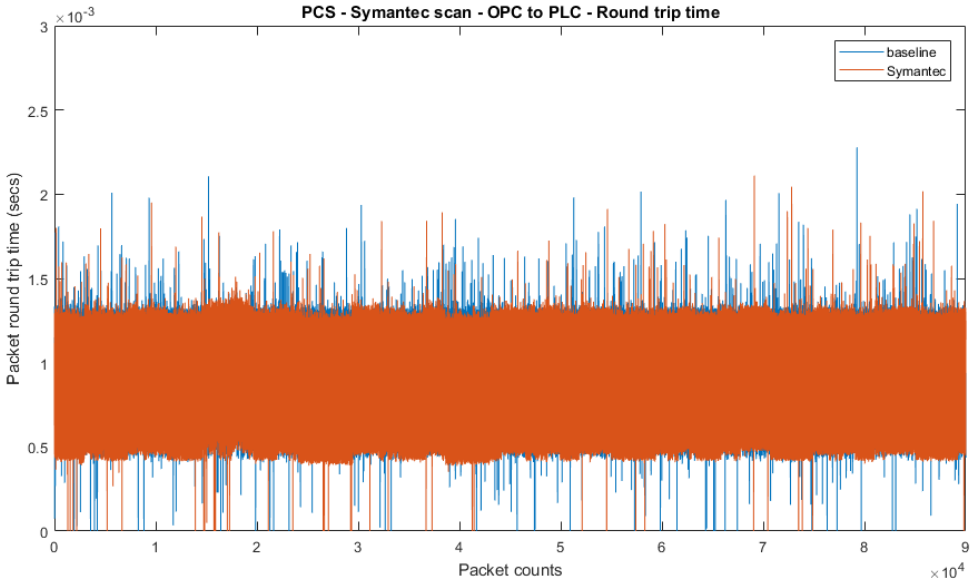


Figure 4-23 Packet round trip time between OPC and PLC during Symantec scan (red)

There was no significant impact to the manufacturing process observed. The product flow and the reactor pressure remain very close to the baseline measurement during the Symantec scan.

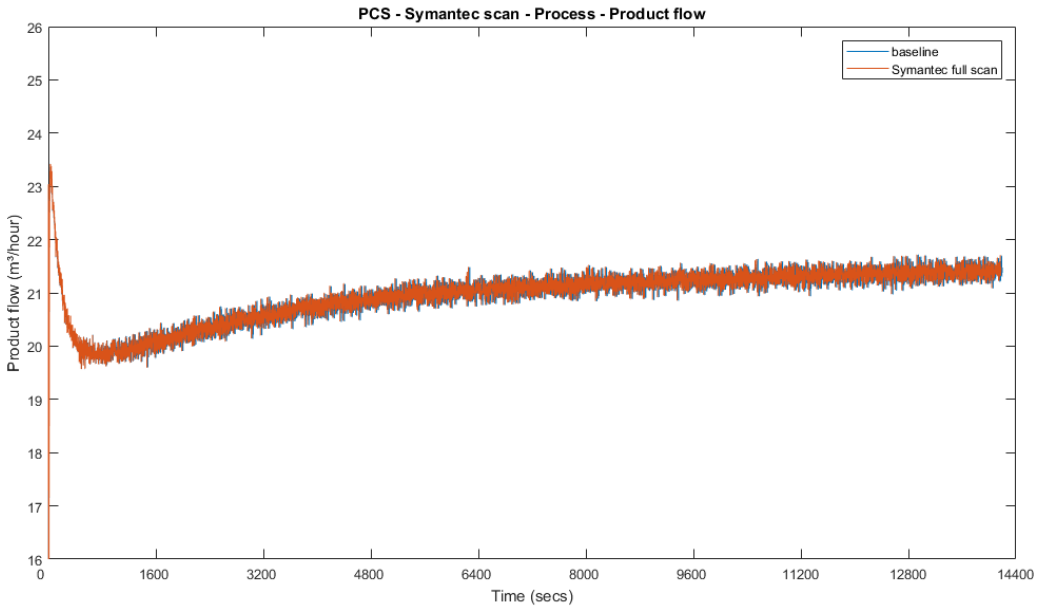


Figure 4-24 Manufacturing process product flow rate

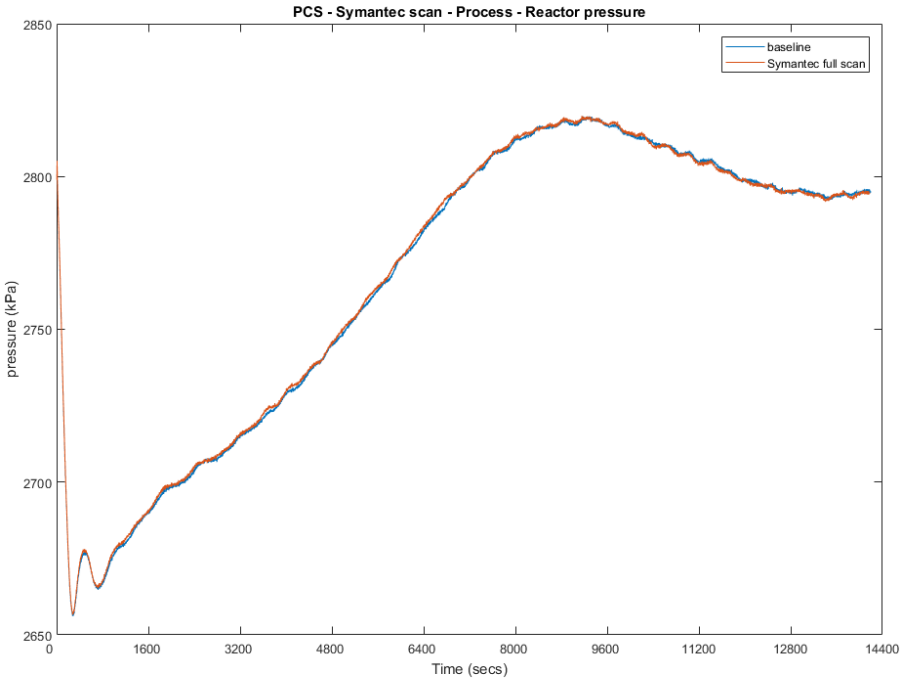


Figure 4-25 Manufacturing process Reactor pressure

It is hypothesized that the impact to the processor utilization was caused by the Symantec AV during the scan. In the case of the PCS system, the normal processor utilization is relatively low and therefore the increased usage did not cause any performance impact to the manufacturing process. If the normal utilization of the host is close to 100 %, there is potential performance impact due to the increase utilization during scan time.

4.10.7 Links to Entire Performance Measurement Data Set

- **Symantec AV KPI data**
- **Symantec AV measurement data**

4.11 Tenable Nessus

4.11.1 Technical Solution Overview

Nessus Professional is a vulnerability assessment software from Tenable. It features high-speed asset discovery, configuration auditing, target profiling, malware detection, sensitive data discovery and more. Nessus supports technologies such as scanning operating systems, network devices, next generation firewalls, hypervisors, databases, web servers and critical infrastructure for vulnerabilities, threats and compliance violations.[94] It supports both authenticated and unauthenticated scans.

Points to consider:

- Easy to setup, User friendly dashboard, fast scanning and can be configured to work in a distributed environment.
- Support for Industrial Protocols such as MODBUS, DNP3 etc. It has the necessary plugins to detect vulnerabilities on ICS/SCADA systems making it ideal to use in OT environments.
- Comes with a variety of Out-of-box policy and configuration templates.
- No limit on number of IPs or number of assessments you can run.
- Support for scanning devices behind a firewall.
- No integration available with LDAP or AD in the Professional edition.
- Multiple user accounts not supported for logging in to the Web UI.

4.11.2 Technical Capabilities Provided by Solution

Tenable Nessus provides components of the following Technical Capabilities described in Section 6 of Volume 1:

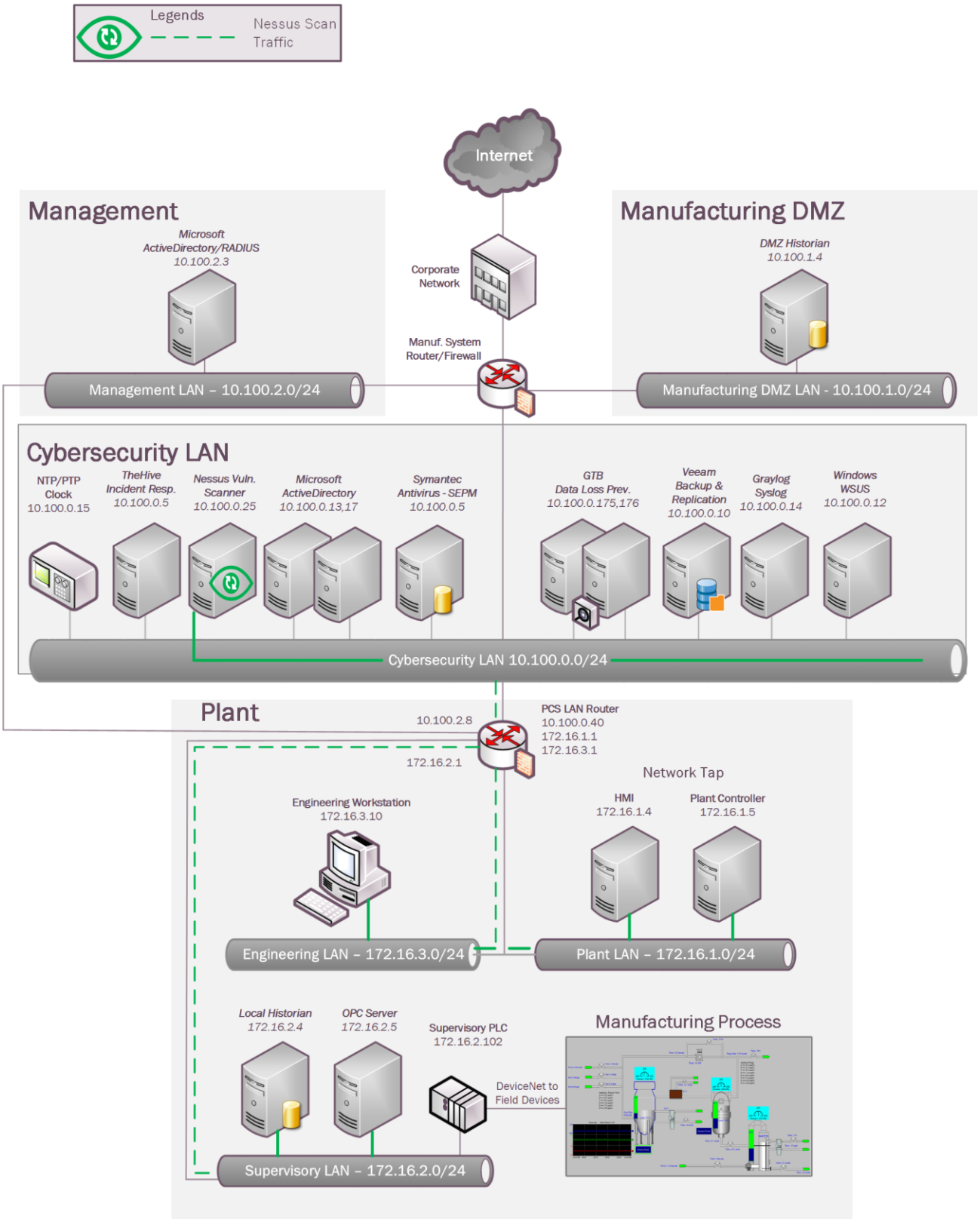
- Vulnerability Scanning
- Vulnerability Management

4.11.3 Subcategories Addressed by Implementing Solution

ID.RA-1, DE.CM-4, DE.CM-8, RS.MI-3

[94] http://info.tenable.com/rs/934-XQB-568/images/NessusPro__DS__EN_v8.pdf

4.11.4 Architecture Map of Where Solution was Implemented



4.11.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Deployment Mode	Hardware Details
Nessus Professional	7.2.0	Standalone	Hyper-V Virtual Machine (Generation 2): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 70 GB • Network: 1 network adapter • OS: Windows 2012 R2

4.11.5.1 Environment setup

1. A virtual machine running Windows 2012 R2 was setup on a Hyper-V host server of the Cybersecurity LAN network of the plant with hardware specifications as described in the table above.
2. The guest OS IP information of this server was set as follows:

```
IP address: 10.100.0.25
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

4.11.5.2 Setup Instructions

1. Download the Nessus Professional installer.[95]
2. Run the installer. Follow the on-screen instructions of the setup wizard.
3. Register the product during installation either in **online** or **offline** mode. An online mode[96] is suitable for environments where Nessus server has internet access while an offline mode is suitable for air-gapped environments.
4. Navigate to the Nessus web interface[97] post installation.
5. Login to the Nessus UI, Click **Settings** to configure SMTP Server, LDAP Server and Custom CA Certificate (if applicable)
6. Configure Firewall rules as described in the Nessus documentation for credentials scans to allow SSH, WMI or SNMP traffic depending on the type of hosts between the Nessus server and the scan targets. For unauthenticated scans, the firewall should be allowed for any-any communication between the Nessus server and target network.

[95] https://www.tenable.com/
[96] https://docs.tenable.com/nessus/Content/ManageNessusOffline.htm
[97] https://<IP address of Nessus server>:8834

4.11.5.3 Configuring Scans and Policies

Prerequisites for performing credentials-based scan of Windows. All of these were enabled on the Windows systems of our Plant network.

- Enable the Windows Management Instrumentation (WMI) service on the target.[98]
- Enable the **Remote Registry** service on the target.
- Enable File and Printer Sharing in the target's network configuration.
- Use an SMB account that has local administrator rights on the target. (You can use a domain account, but that account must be a local administrator on the devices being scanned.)
- Open Ports 139 (TCP) and 445 (TCP) between the Nessus scanner and the target.
- Enable the default administrative shares (i.e. IPC$, ADMIN$, C$) (**AutoShareServer** = 1). These are enabled by default and can cause other issues if disabled.[99]
- Run the commands below from an elevated Command prompt or PowerShell (Right click **CMD** > **Run as administrator**) on a host in the same network as the target.

```
net use \\<IP-address of Target>\ipc$/user:
```

This command will test if we can access the IPC$ share without a username (This is how Nessus tests to see if SMB is running)

```
net use \\x.x.x.x\ipc$ /user:username password
net use \\x.x.x.x\admin$ /user:username password
```

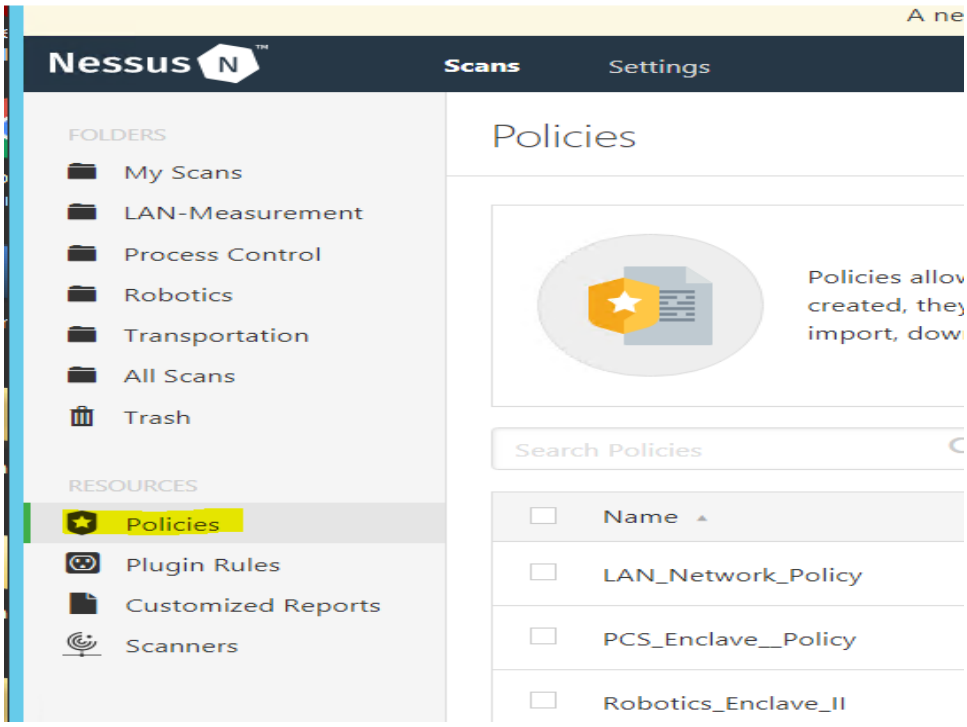
These commands are for SMB Logon test. These commands should return "The command completed successfully." If it does not, then the credentials did not work or do not have sufficient privileges.

Note: To have a successful credential scan, these commands should not return errors.

Use the **Policy** feature of Nessus for performing credentials checks, A Policy lets you create a scan template where in device credentials and other custom settings can be saved for scanning assets. Once created, a policy can then later be assigned to a scan**.**

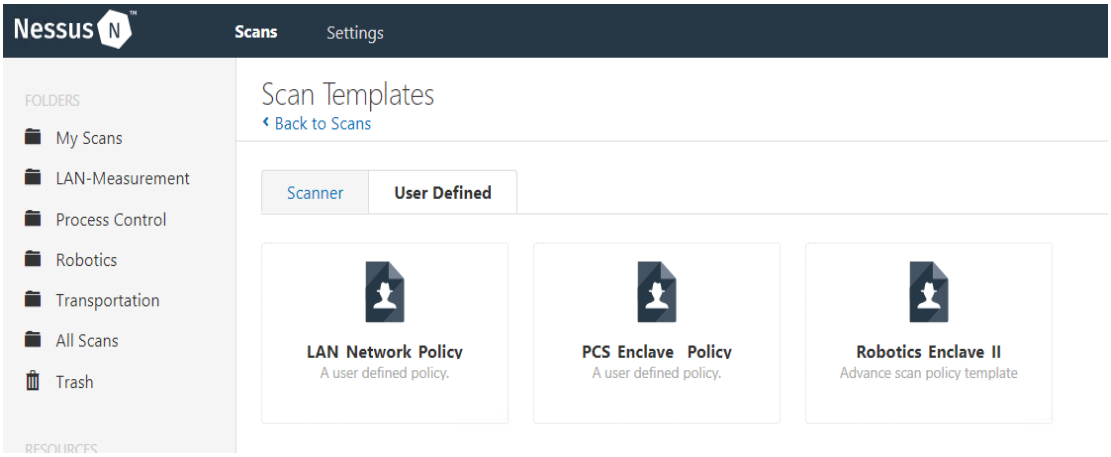
[98] https://technet.microsoft.com/en-us/library/cc180684.aspx
[99] http://support.microsoft.com/kb/842715/en-us.

1. Create a Policy using the following instructions
    a. Click on **Policies** from the left-side explorer bar
    b. Click on **New Policy** button.



    c. Choose from any on the default templates available. The **Advanced Scan** template was selected for our use. Click on Credentials tab under a template to configure host-based credentials (SSH, Windows, SNMP, etc.).
    d. Click **Save** when done.

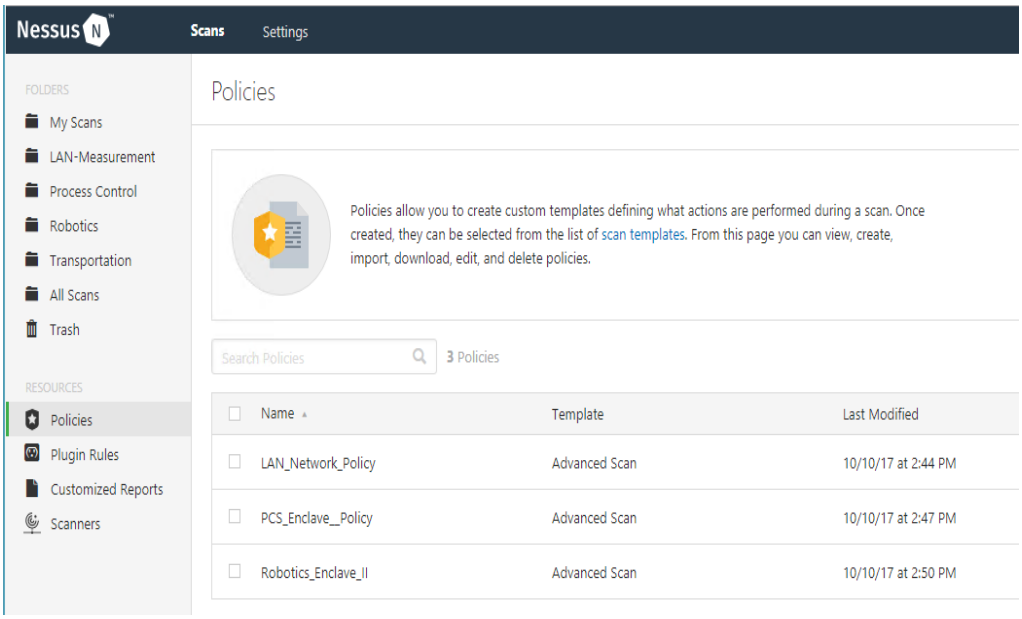
2. Create a Scan using the following instructions
    a. Click **Scans** on the Home Page > +**New Scan > User Defined > Select <Policy>**
    b. Enter **a Name, Description** and **Network Range or Host IP addresses.**
    c. Click on **Schedule** to configure a schedule
    d. Click **Notifications** to configure Email recipients.
    e. Click **Save.**



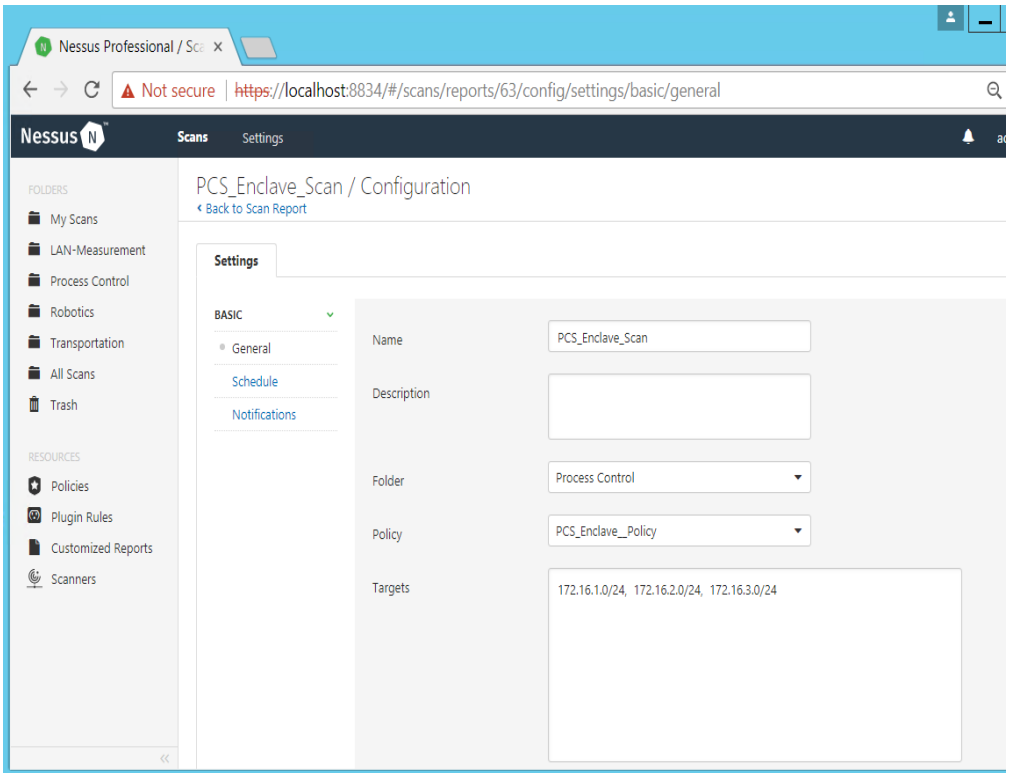
3. Assign the Scan created to a Policy as follows
    a. Click **All Scans** > Click on the **<Scan>** created earlier.
    b. Under **Policy**, Select the appropriate Policy from the drop-down list to associate the scan with a policy.
    c. Click **Save**.
4. (Optional) Click on the launch button next to the scan to start on-demand scan
5. Review the scan results upon completion of the scan.

4.11.5.4 Custom Configuration for the Plant Network

The figure below shows the different policies created in our Nessus Manager specific to each system. The policy for this Process Control system is named **PCS_Enclave_Policy**



The figure below shows the corresponding scan job settings which has the **PCS_Enclave_Policy** assigned to it.



4.11.5.5 Additional Information

- Official Nessus Documentation[100]
- Credentials checks for scanning Windows targets[101]

[100] https://docs.tenable.com/nessus/Content/GettingStarted.htm
[101] https://docs.tenable.com/nessus/Content/CredentialedChecksOnWindows.htm

4.11.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Nessus vulnerability assessment tool while the manufacturing system was operational:

Experiment PL006.1- Nessus vulnerability network scan

There was no significant performance impact to the manufacturing process observed during the Nessus vulnerability scan. No significant network traffic increased during the Nessus scan was observed. For example, the packet round trip time from the Controller to OPC stayed mostly constant throughout the Nessus scan.

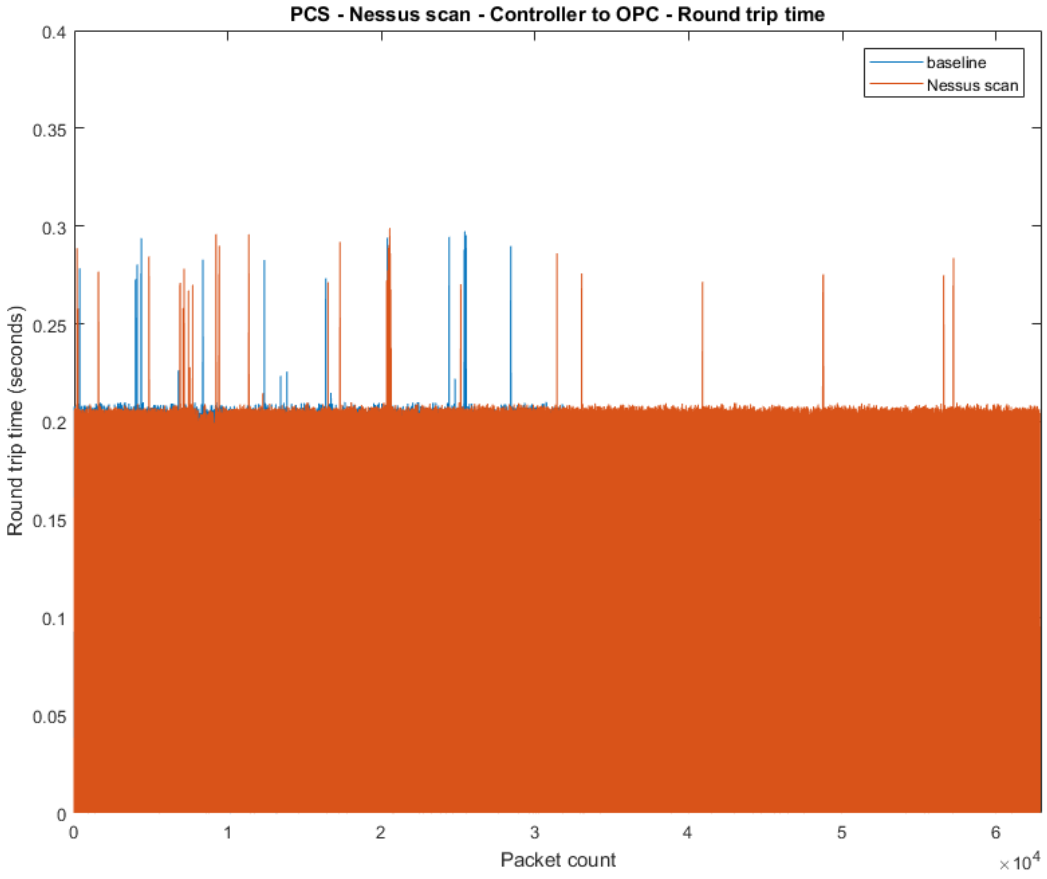


Figure 4-26 Packet round trip time from Controller to OPC during Nessus scan

Some part of the system recorded a slightly increased network traffic, for example, the network utilization and average bit rate from OPC to HMI during the Nessus scan was about 14.11 % and 1.41 Mbit/sec respectively, while the baseline is 13.81 % and 1.38 Mbit/sec respectively. The

network utilization from PLC to OPC during the Nessus scan was about 2.2 % higher than baseline.

The performance of the manufacturing process mostly remained the same. For example, the product flow and the reactor pressure remained align with the baseline measurement.

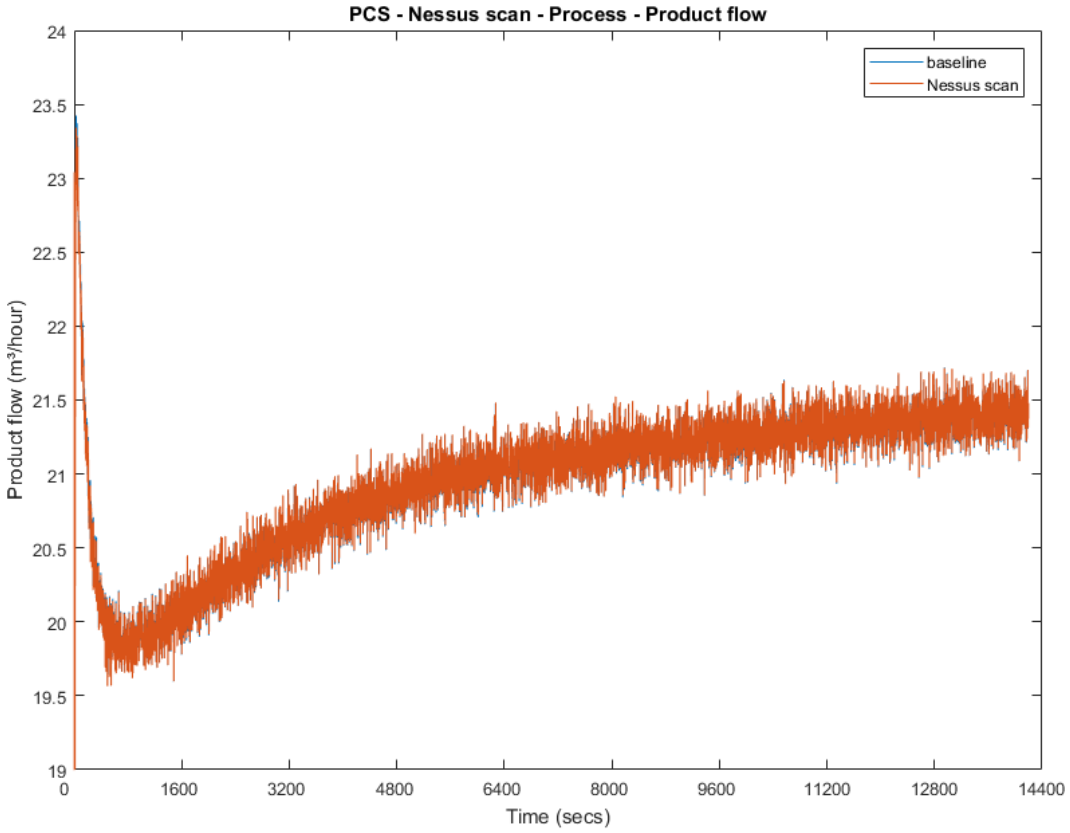


Figure 4-27 Manufacturing process product flow rate at Nessus scan

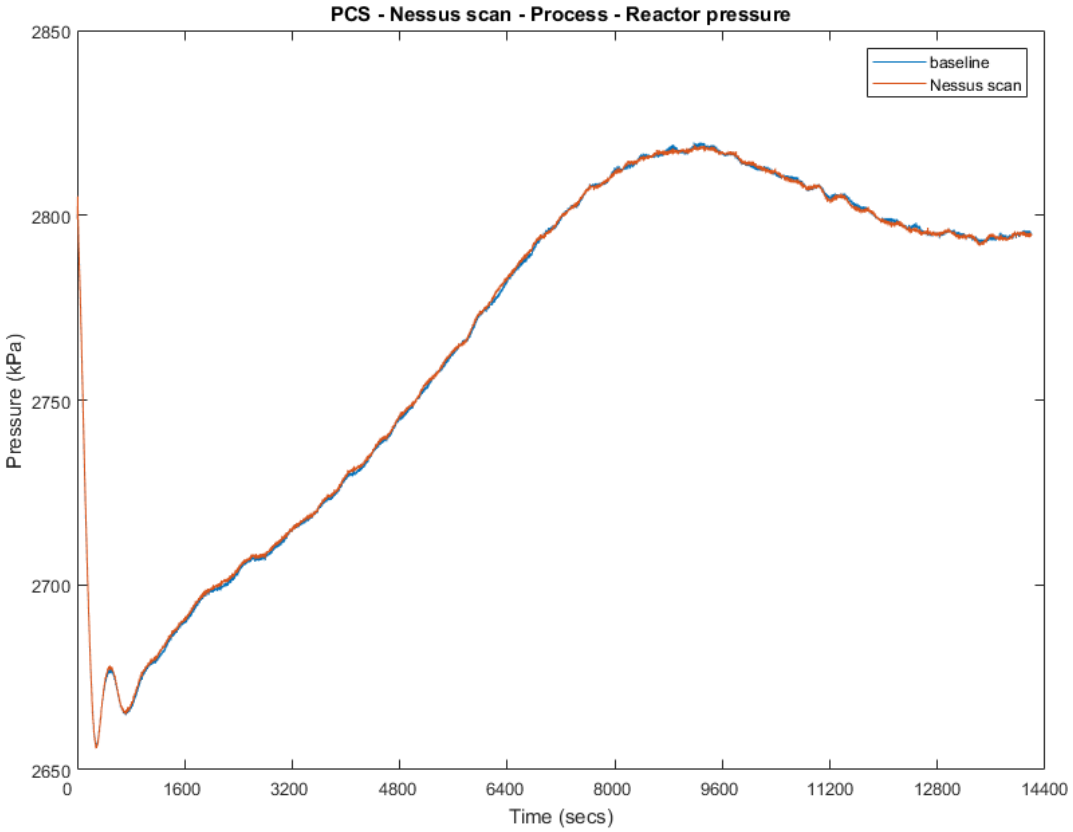


Figure 4-28 Manufacturing process reactor pressure at Nessus scan

4.11.7 Links to Entire Performance Measurement Data Set

- **Nessus KPI data**
- **Nessus measurement data**

4.12 NamicSoft

4.12.1 Technical Solution Overview

NamicSoft Scan Report Assistant is a parser and reporting tool for Nessus, Burp, Nexpose OpenVAS and NCATS.[102]

4.12.2 Technical Capabilities Provided by Solution

NamicSoft provides components of the following Technical Capabilities described in Section 6 of Volume 1:

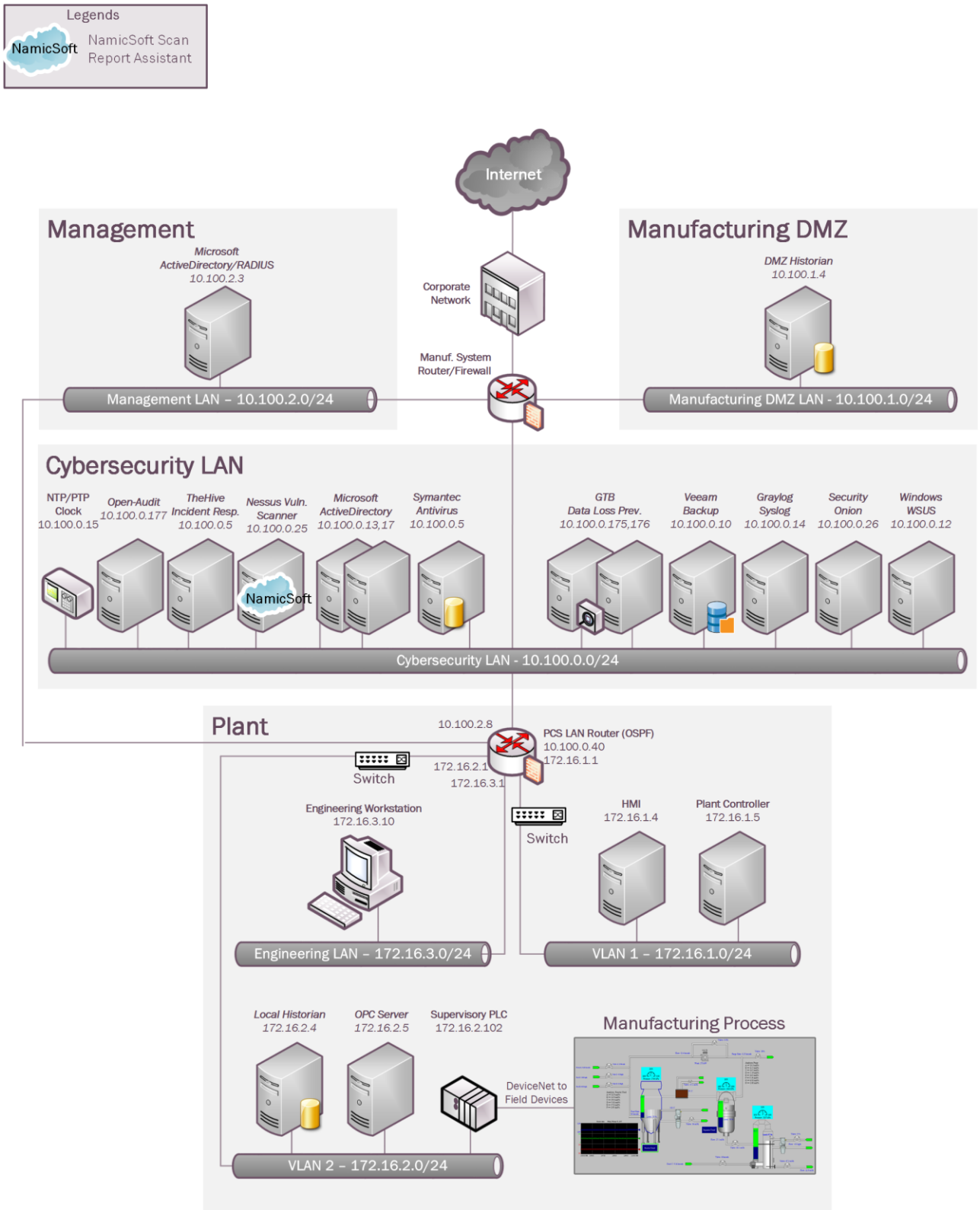
- Vulnerability Management

4.12.3 Subcategories Addressed by Implementing Solution

ID.RA-1, DE.CM-4, RS.MI-3

[102] https://www.namicsoft.com/

4.12.4 Architecture Map of Where Solution was Implemented



4.12.5 Installation Instructions and Configurations

Details of the solutions implemented:

Name	Version
NamicSoft Scan Report Assistant	3.5.0

4.12.5.1 Environment setup

1. NamicSoft was installed on our Nessus Scanner server as described in Section 4.11.
2. The guest OS IP information of this server was set as follows:

```
IP address: 10.100.0.25
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

4.12.5.2 Setup Instructions

1. Download NamicSoft[103]
2. Run the installer on a Windows PC. NamicSoft is currently supported on 64-bit Windows with .Net Framework 4.5 installed
3. Launch the program by double clicking its Desktop icon. If using for the first time, the installation will prompt for a license file. If a license is not entered, it runs in free mode. The free mode is limited to five hosts.

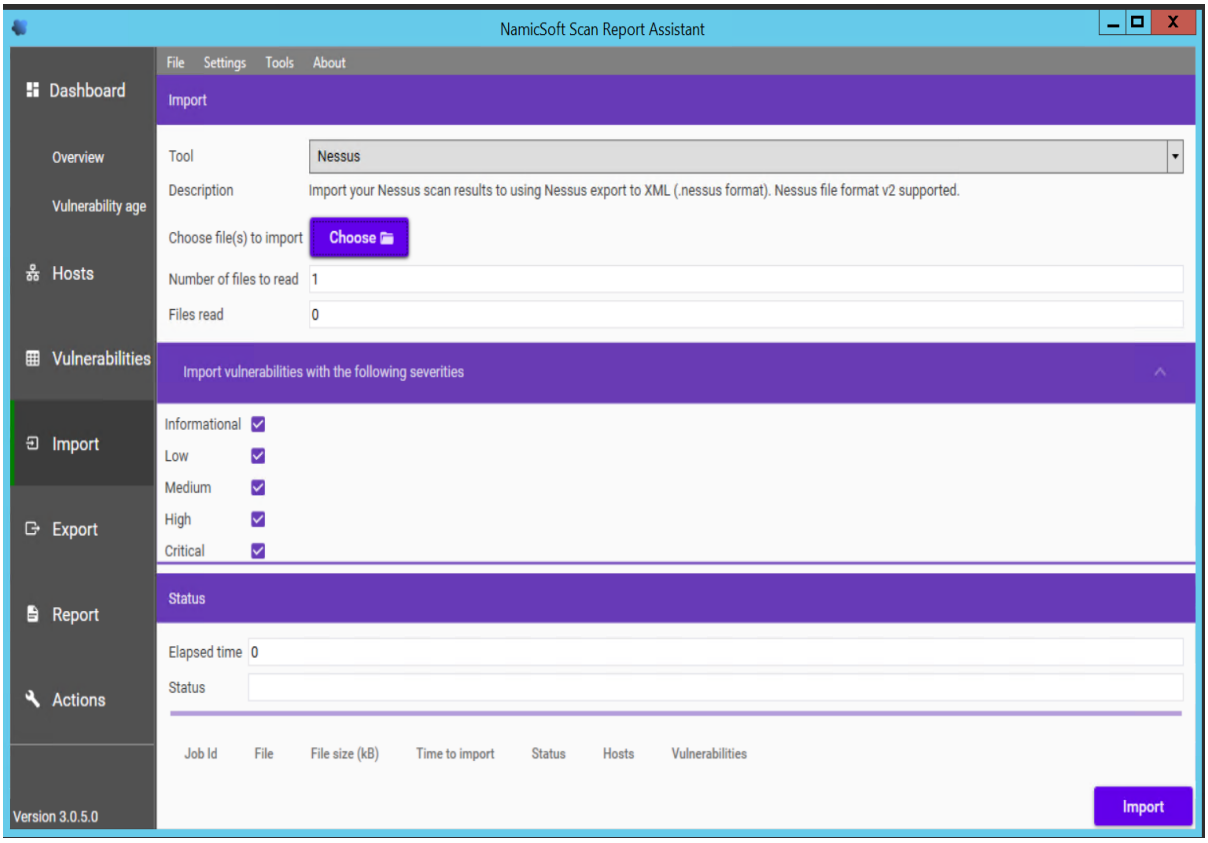
Note: The software is tied to a Windows user account. Any changes made by a user would not be visible to a different user logging in to the same system.

4.12.5.3 Configuration for reporting Nessus scans

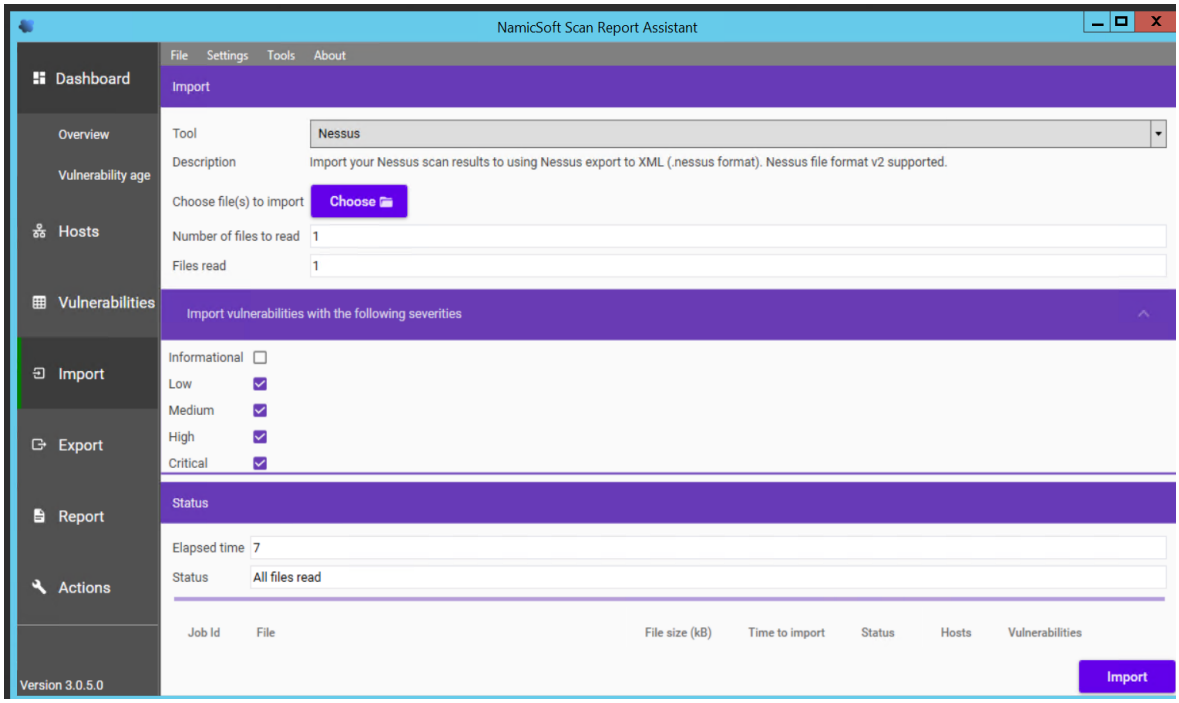
1. Export a Scan Report of **Nessus** format from the Nessus web interface.
2. Launch NamicSoft Report Assistant. Click **Import** on left-side explorer, select **Nessus**

[103] https://www.namicsoft.com

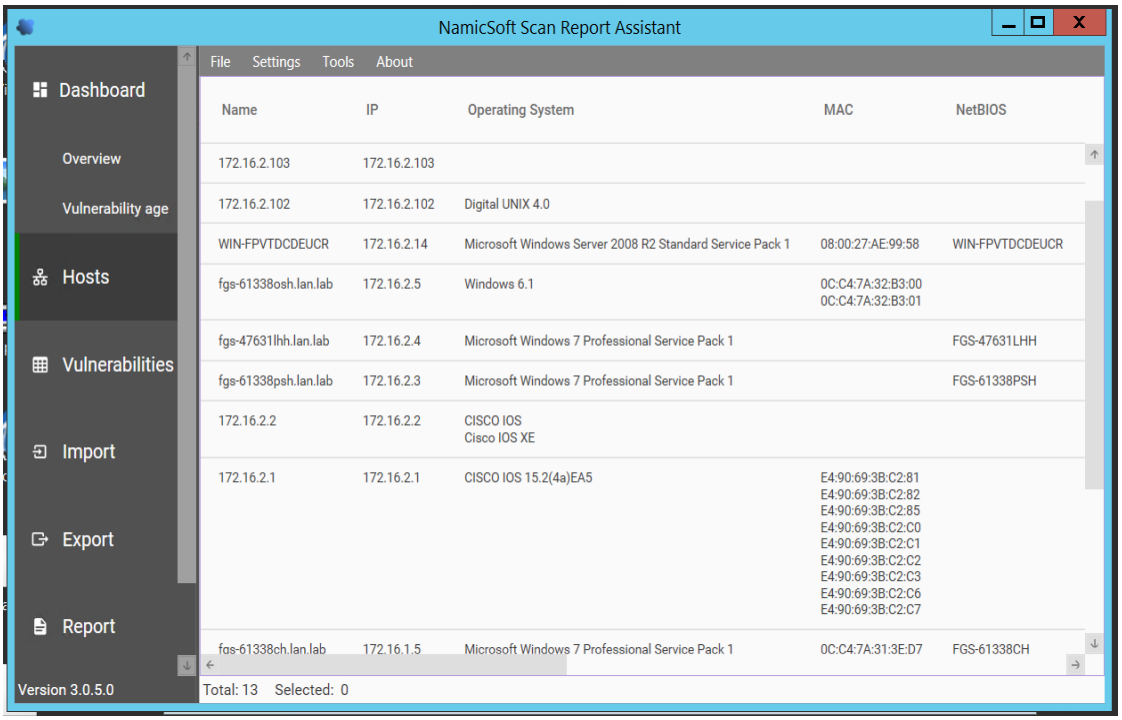
3. Click on **Choose** button to import files

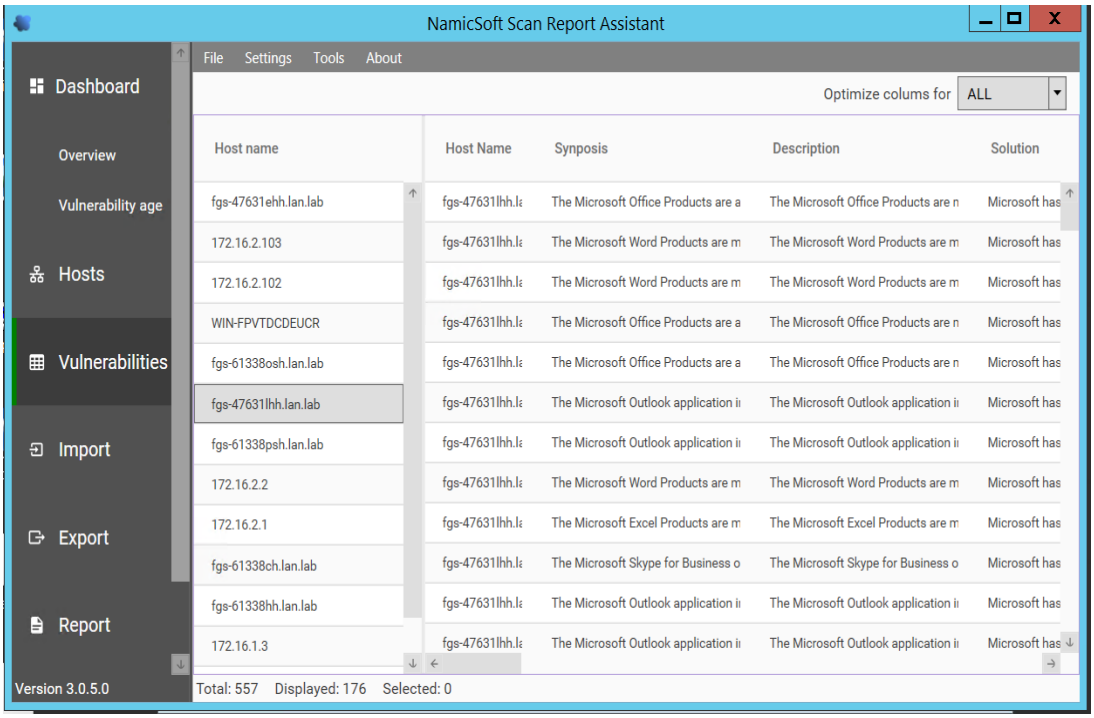


4. Browse to the Nessus scan report. Under **Import Vulnerabilities with following vulnerabilities,** Check / Uncheck whichever severity of vulnerabilities you wish to be included in the report and click **Import.**
   For instance, the image below shows **Informational** types being excluded and other severity levels such as **High, Critical, Medium Low** being selected. When the **Import** finishes, the Status bar should display **All files read**.

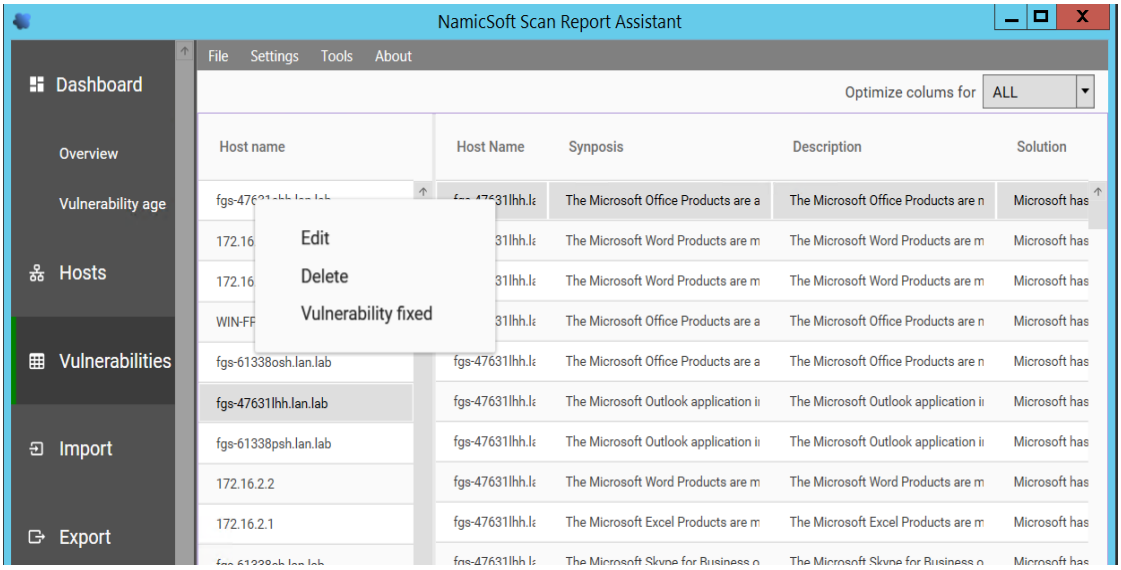


5. Click the **Hosts** page upon completion of Import, to view all the hosts level summary. Similarly, clicking on **Vulnerabilities** page shows all the vulnerabilities



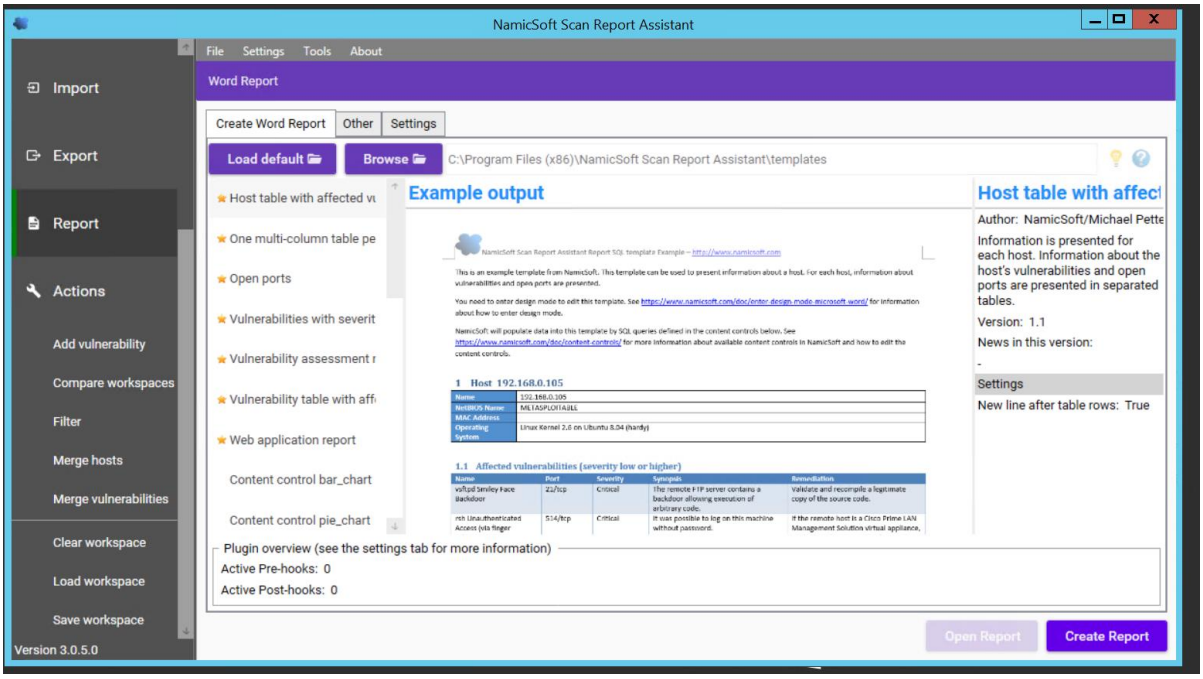


6. (Optional) Mark a Vulnerability as Fixed by selecting the Vulnerability > Right Click > **Vulnerability Fixed.**

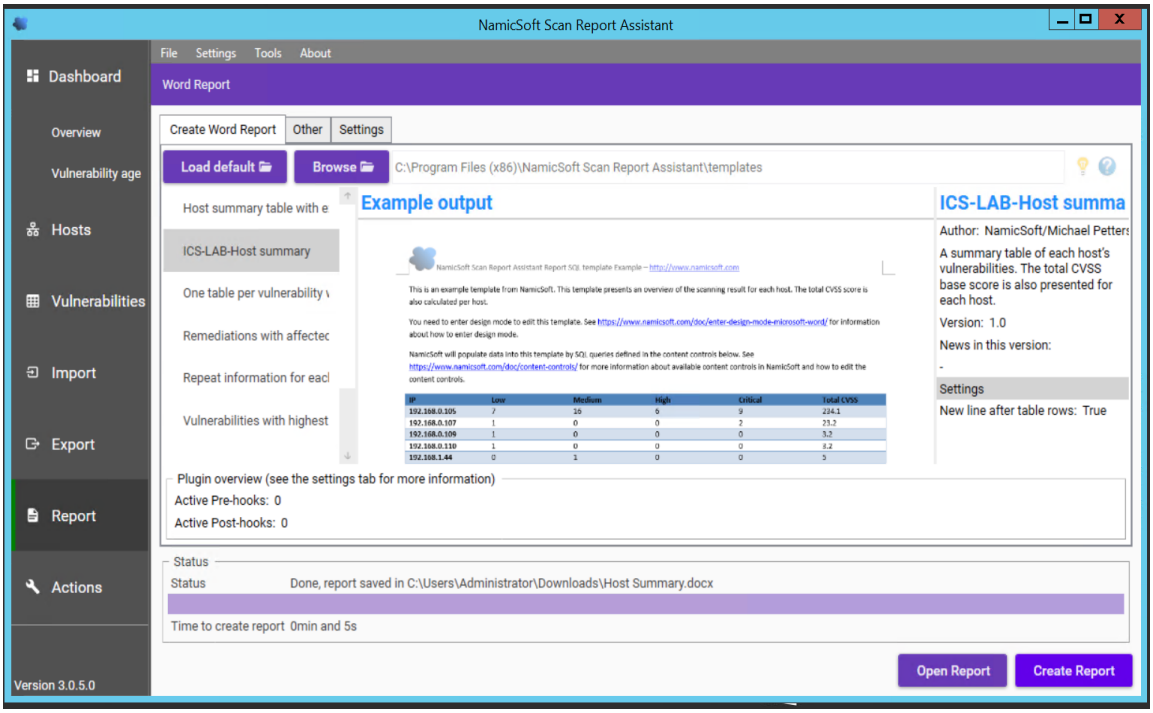


7. Click on **Save Workspace** under **Actions**. Ensure to **Save your workspace** after every change made. When running NamicSoft the next time, you can load this saved workspace file.

8. Click on **Report** as shown below to generate a report**.** Select one of the default reporting templates from the list or create a custom one. To use a default template, select one from the list >> **Create Report.**



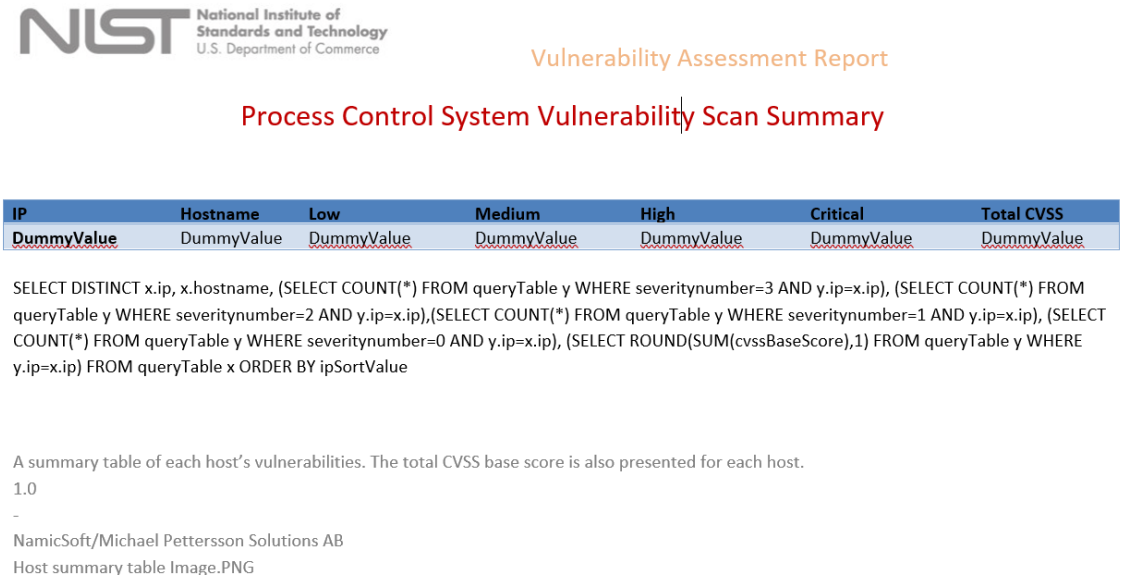
9. Click **Open Report** to view the Report**.**



4.12.5.4 Creating Custom Template

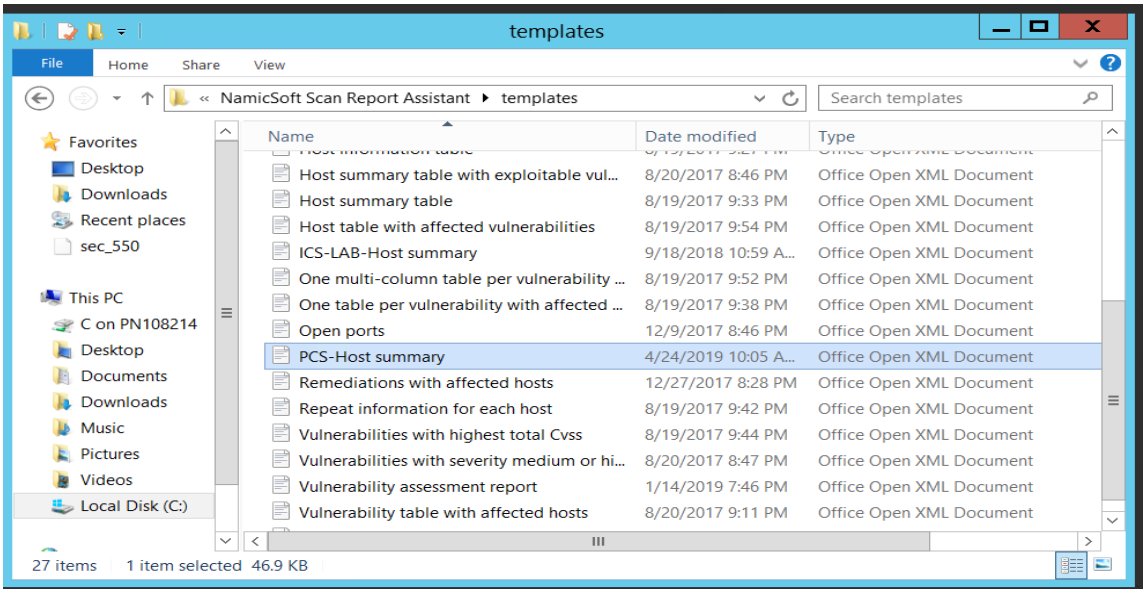
1. Copy one of the existing template files located under *C:\Program Files(x86)\NamicSoft Scan Report Assistant\templates* and save it to a different folder.
2. Open the copied file in MS Word to begin editing. The image below shows a customized template file created for Process Control System. This report generates a summary of hosts and their respective vulnerabilities based on the Severity level.

   Custom reports[104] can also be created.

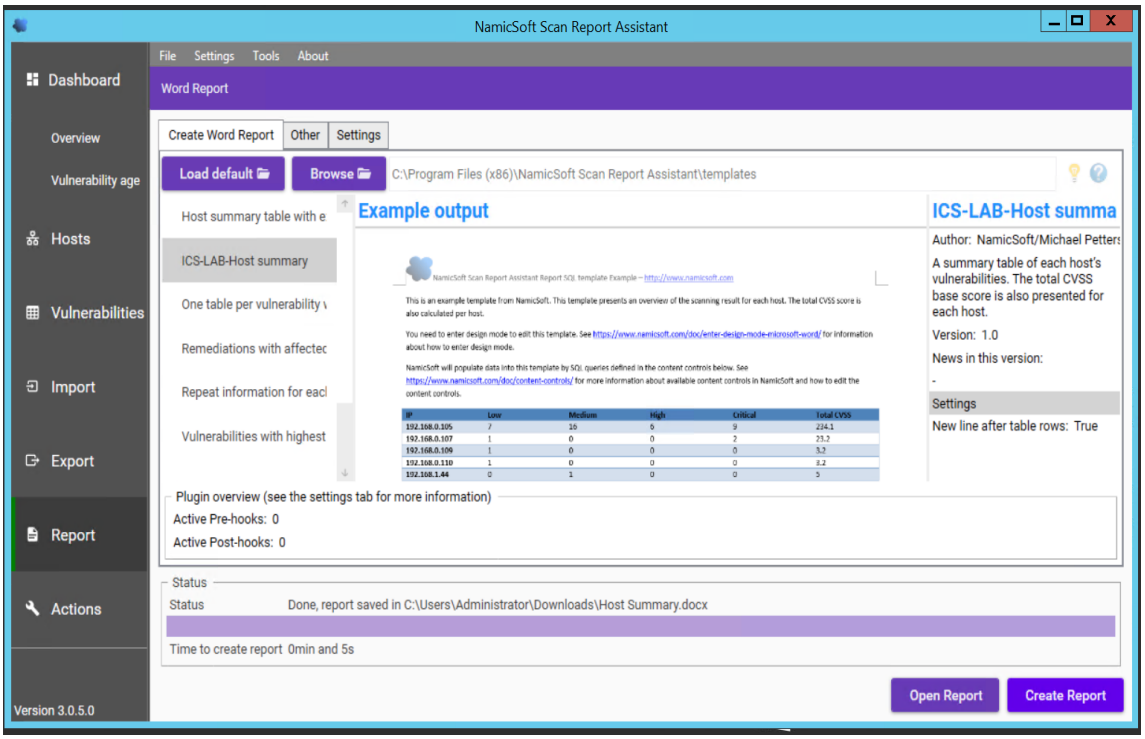


3. Save your changes and give the file a name.
4. Copy this file back to the *templates* directory on the NamicSoft machine. For instance, the image below shows our customized file – **PCS- Host Summary** copied back to the *templates* folder.

[104] https://www.namicsoft.com/doc/content-controls/



5. Launch NamicSoft again. The custom report should now appear under the list. Select it and click on **Create Report.**



6. Review the output to confirm your changes.

Vulnerability Assessment Report

Process Control System Vulnerability Scan Summary

IP	Hostname	Low	Medium	High	Critical	Total CVSS
172.16.1.1	172.16.1.1	4	6	2	0	58.6
172.16.1.3	172.16.1.3	1	6	0	0	36.2
172.16.1.4	fgs-61338hh.lan.lab	3	26	39	6	542.3
172.16.1.5	fgs-61338ch.lan.lab	3	24	42	5	547.6
172.16.2.1	172.16.2.1	4	6	2	0	58.6
172.16.2.2	172.16.2.2	0	6	0	0	33.6
172.16.2.3	fgs-61338psh.lan.lab	2	23	41	5	538.3
172.16.2.4	fgs-47631lhh.lan.lab	3	40	122	11	1420.3
172.16.2.14	WIN-FPVTDCDEUCR	3	18	92	11	1047.5
172.16.3.10	fgs-47631ehh.lan.lab	0	0	0	1	10

7. (Optional) Use the **Compare Workspaces** feature under Action Menu to report on Vulnerabilities remediated based off the previous vulnerability scans as follows

   a. Load Nessus result from your previous scan. Save as a **workspace**.
   b. Clear the workspace in the GUI (or restart NamicSoft)
   c. Load Nessus results from the latest scan
   d. Open **Actions** > **Compare workspaces**. Choose **Compare** with current workspace and point Workspace 2 to your workspace saved earlier.
   e. Choose **Excel output file (target)**
   f. Click Compare Workspaces

4.12.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the use of NamicSoft due to its installation location and how it was used (i.e., the software performed offline analysis of vulnerability data captured by other software at a location external to the manufacturing system).

4.12.7 Links to Entire Performance Measurement Data Set

N/A

4.13 The Hive Project

4.13.1 Technical Solution Overview

A scalable, open source and free Security Incident Response Platform.[105]

4.13.2 Technical Capabilities Provided by Solution

The Hive Project provides components of the following Technical Capabilities described in Section 6 of Volume 1:

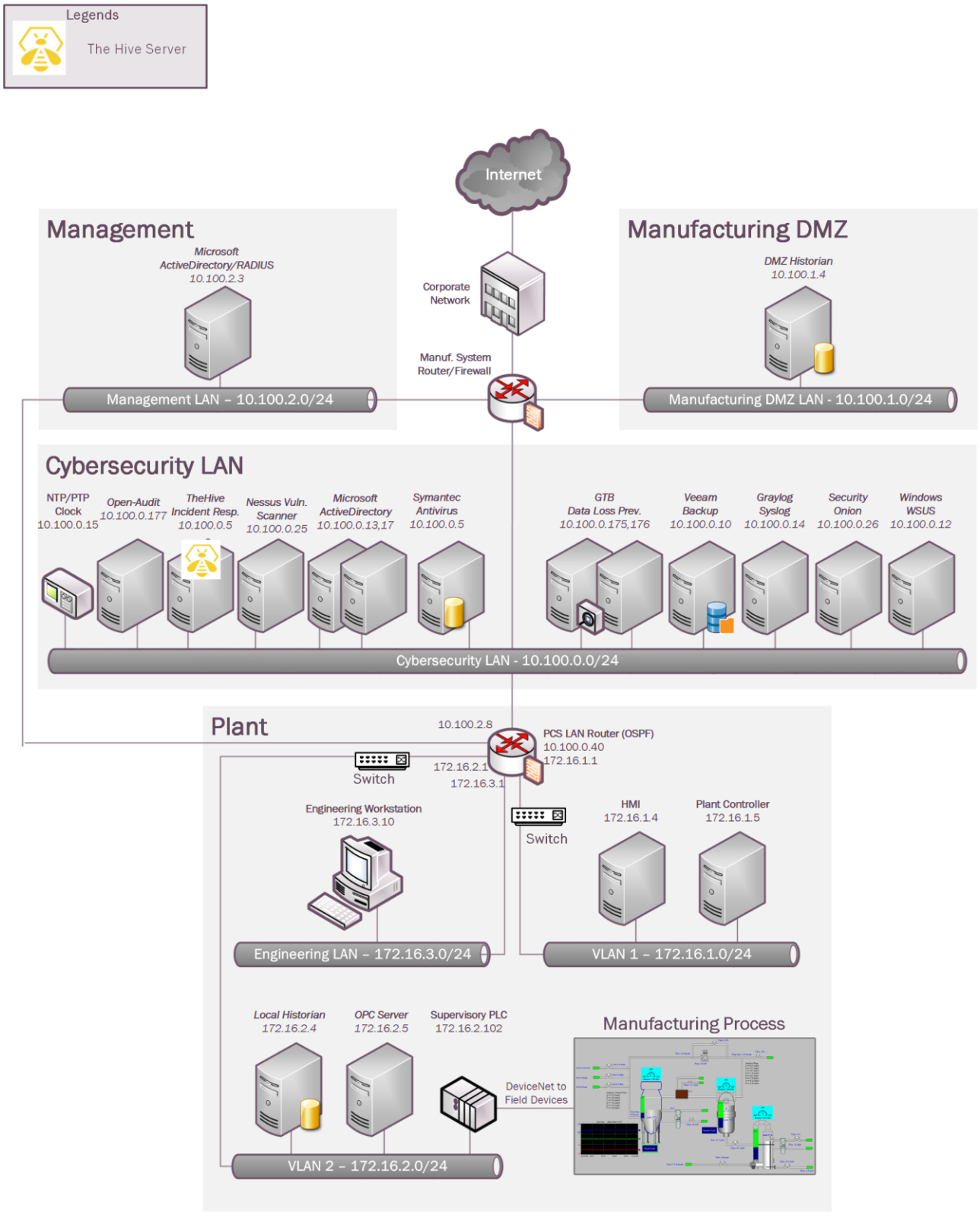
- Incident Management

4.13.3 Subcategories Addressed by Implementing Solution

RS.MI-2, RS.MI-3

[105] https://thehive-project.org/

4.13.4 Architecture Map of Where Solution was Implemented



4.13.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware Details
TheHive	3.0.10	Hyper-V Virtual Machine • Processors: 2 virtual cores • Memory: 4 GB • Disk space: 50 GB • Network: 1 interface • Operating System: Ubuntu 16.04

4.13.5.1 Environment Setup

1. A preconfigured training VM as provided by the Vendor was deployed on Hyper-V host server with the hardware specifications as described above.
2. The guest OS IP information was set as follows:

```
IP address: 10.100.0.51
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

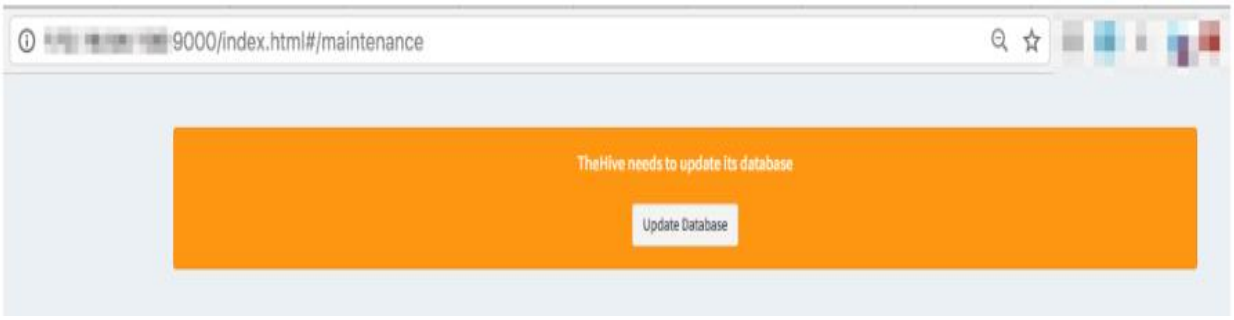
4.13.5.2 Setup Instructions

1. Download the software[106]
2. Install the binaries on a supported version of Linux.[107]
3. Complete the setup process as per the instructions. Once done, **TheHive** can be accessed from http://<ip-address_of_hive_server>:9000

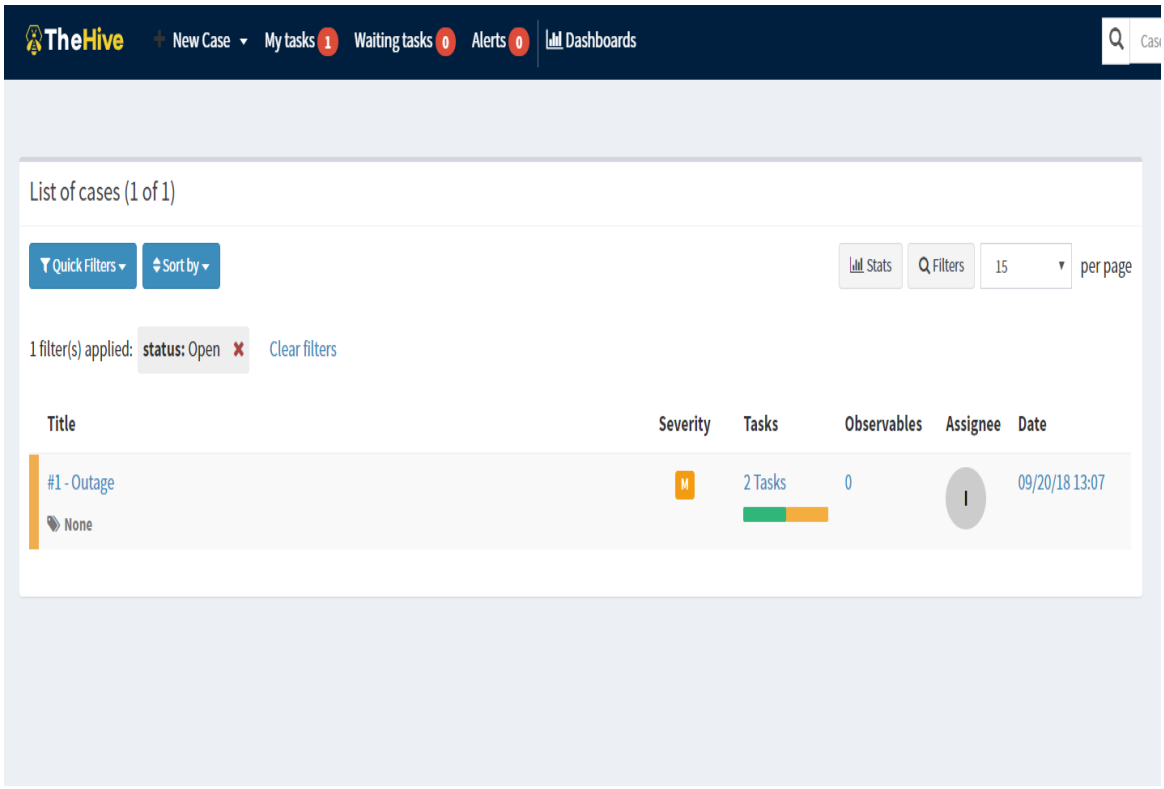
[106] https://github.com/TheHive-Project/TheHive
[107] https://github.com/TheHive-Project/TheHiveDocs/blob/master/installation/install-guide.md

4.13.5.3 Additional Setup via Web Browser

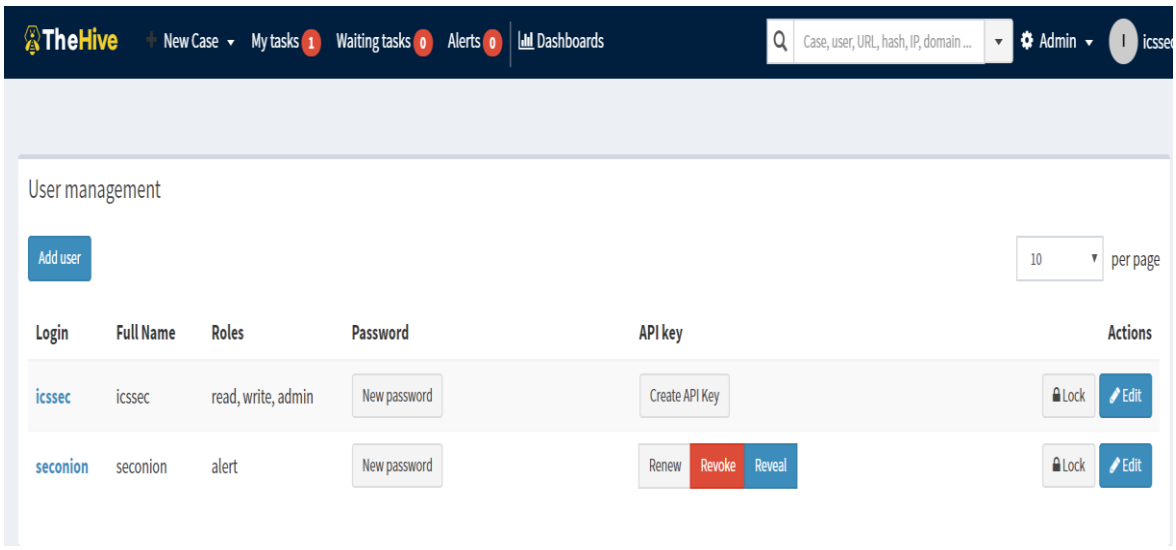
1. Create the associated database if accessing **TheHive** for the first time, by clicking on the **Update Database** button as shown below:



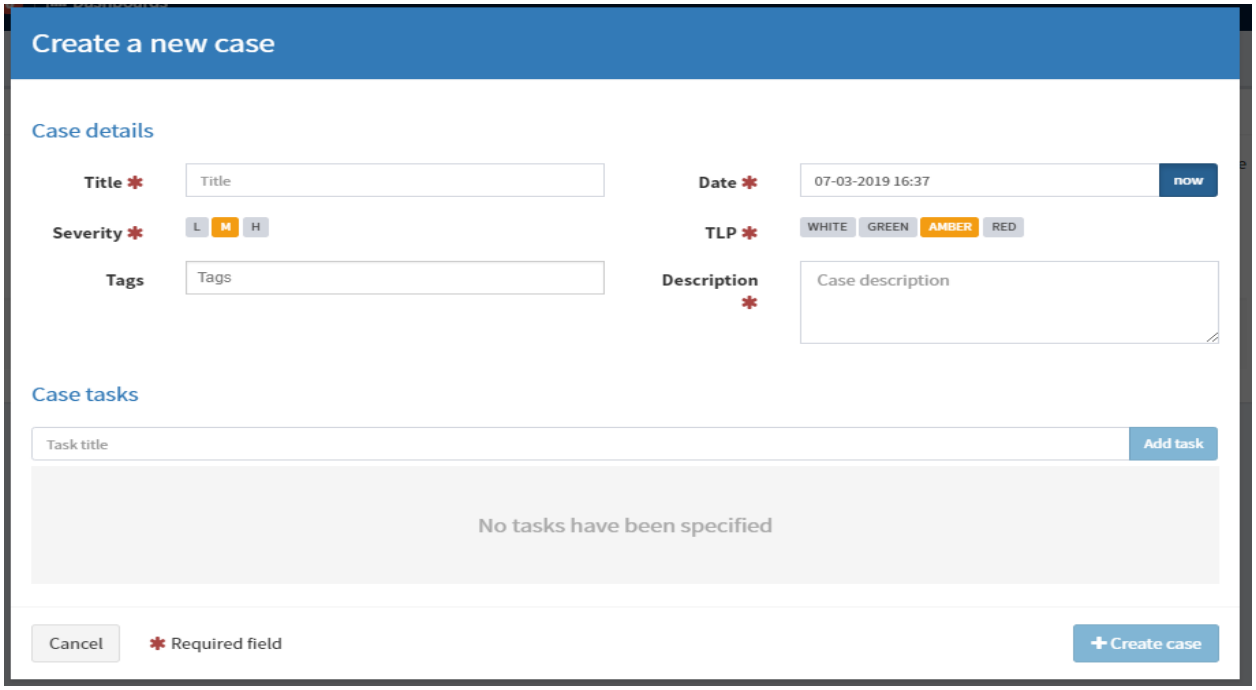
2. Follow the wizard to setup a user account.
3. Login to **TheHive** URL with these credentials. The default page will show you a List of Cases assigned to your account. There will be none initially for a new setup.



4. Click on **Admin > Users > User Management** page, to create Additional user accounts. Click on **+Add User** to create a new user.

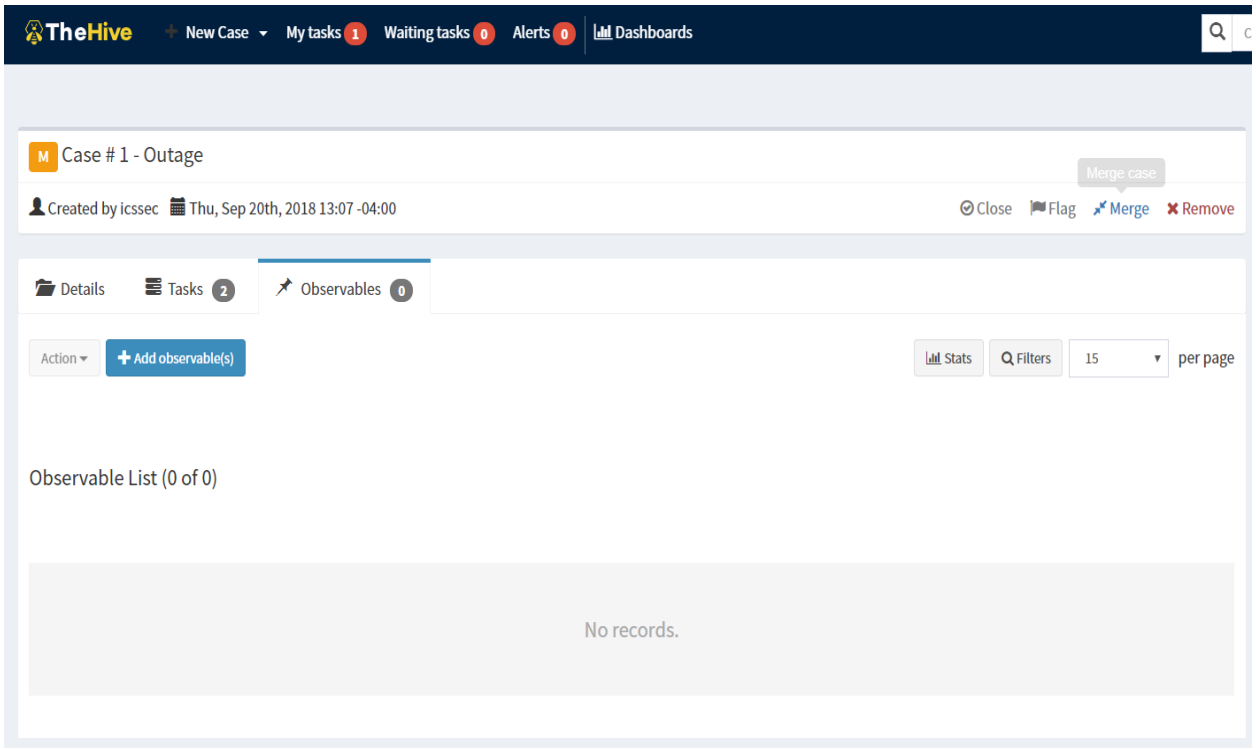


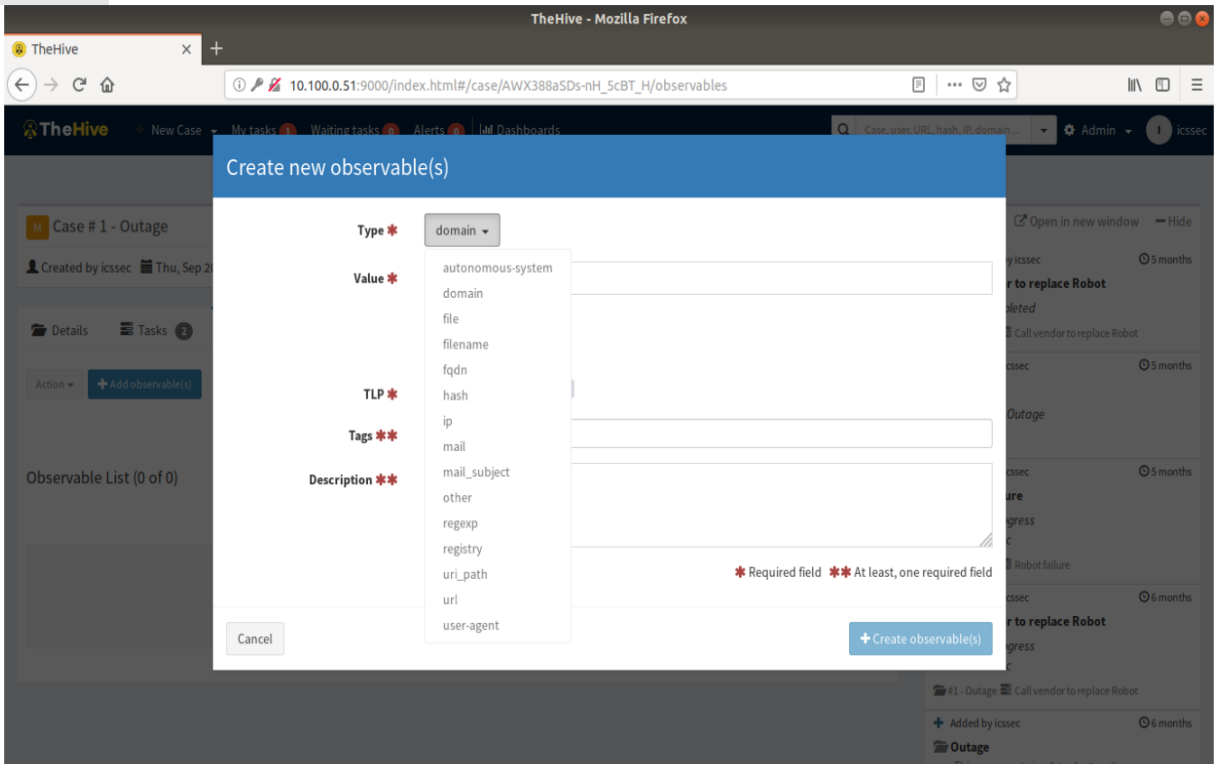
5. Create a new Incident / case as follows:
   a. Click on the **New Case** menu option
   b. Fill in all the details.
   c. Click on **Add Task** to add a task under a case. Each task can be individually assigned to an analyst for the work to be performed. By default, a task doesn't have an owner until someone clicks into it, or "takes" it from the Waiting tasks queue in the top menu bar.
   d. Hit **Create Case** button when done.



6. Create a Custom Case Template as follows:
    a. Click on **Admin > Case Templates** button on top right-hand corner
    b. Click +**New Case Template**
    c. Fill out the information in the fields.
    d. Click **Save Case Template**

7. (Optional) Open up a **Case** and click on **Observables** tab > **+Add Observables** to add Custom Observables such as domain names, IP addresses, files, filenames etc. to a case. In addition, observables can also be marked as Indicators of Compromise (IOC).





8. (Optional) Use the Cortex engine[108] via http://<ip_of_hive_server>:9001 to perform detailed analysis on observables or IOCs such as domain names, IP addresses, hashes. This can be achieved by enabling or creating Analyzers in Cortex.

   The high-level steps in configuring Cortex are:

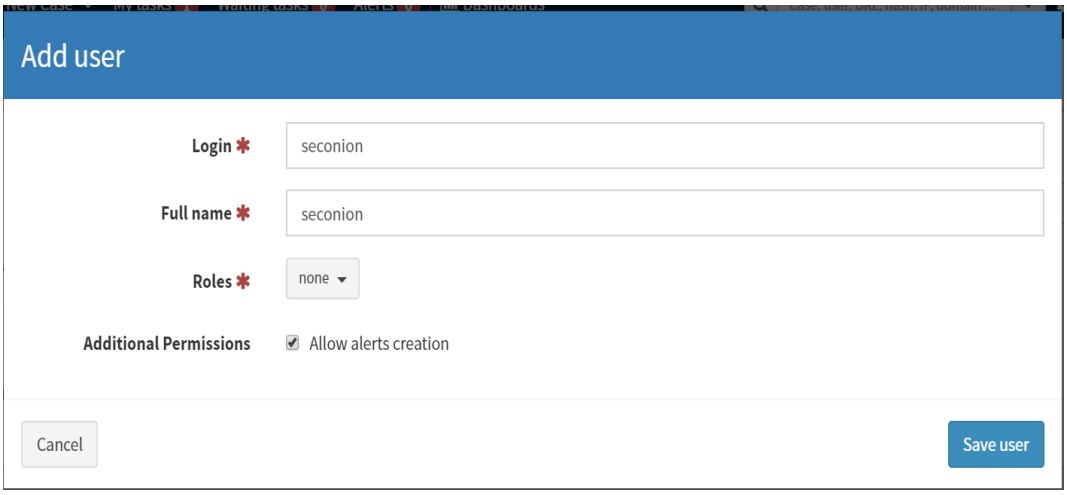
   a. Setup Cortex
   b. Create an Administrator account
   c. Create an Organization
   d. Create an Organization Administrator account
   e. Enable or Configure Analyzers
   f. Integrate with the Hive instance

[108] https://github.com/TheHive-_Project/CortexDocs

4.13.5.4 Integration with Security Onion

Our Security Onion instance was integrated with the Hive Instance to create a case for IDS alerts generated by Security Onion.

1. Create a dedicated user account in Hive with permissions to **Allow alerts creation**. Ensure **Roles: None** is set for security purposes of this user account.



2. Click on **Create API Key** to create an API key for this user

3. (To be performed on the Security Onion server) Create a new rules file **hive.yaml** under the */etc./elastalert/rules* directory of the Security Onion server mentioning the IP address of the Hive Server as shown below.[109]

```
# hive.yaml
# Elastalert rule to forward IDS alerts from Security Onion to a specified TheHive instance.
#
es_host: elasticsearch
es_port: 9200
name: TheHive - New IDS Alert!
type: frequency
index: "*:logstash-ids*"
num_events: 1
timeframe:
   minutes: 10
buffer_time:
   minutes: 10
allow_buffer_time_overlap: true

filter:
- term:
   event_type: "snort"

alert: hivealerter

hive_connection:
  hive_host: https://10.100.0.51
  hive_port: 9000
  hive_apikey: APIKEY
```

4.13.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the use of the Hive Project due to its typical installation and usage location (i.e., external to the manufacturing system).

4.13.7 Links to Entire Performance Measurement Data Set

N/A

[109] https://securityonion.readthedocs.io/en/latest/hive.html#thehive.

4.14 Microsoft EFS

4.14.1 Technical Solution Overview

EFS is a file level encryption tool provided by Windows. The Encrypted File System, or EFS, provides an additional level of security for files and directories. It provides cryptographic protection of individual files on NTFS file system volumes using a public-key system.[110]

4.14.2 Technical Capabilities Provided by Solution

Microsoft EFS provides components of the following Technical Capabilities described in Section 6 of Volume 1:

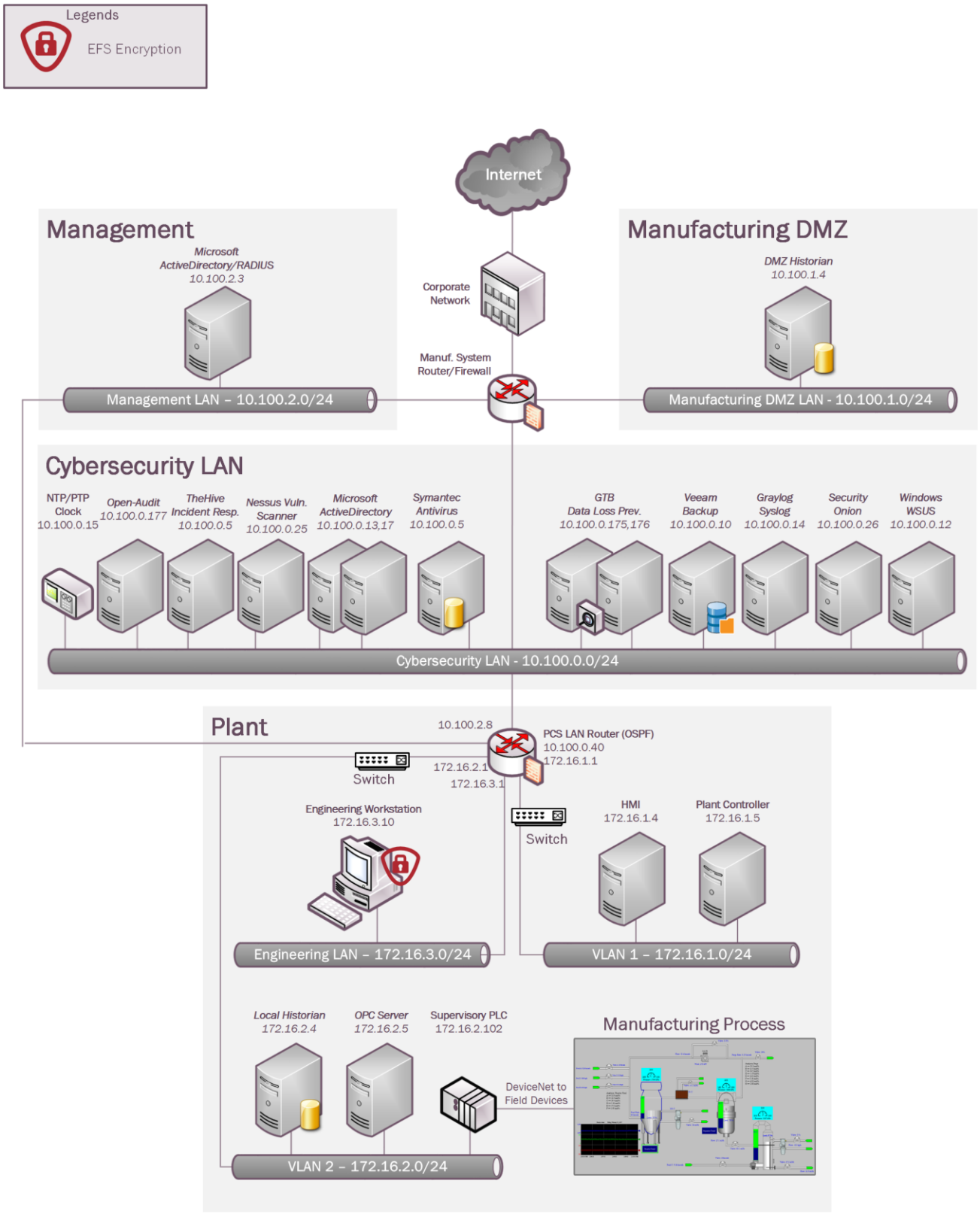
- Encryption

4.14.3 Subcategories Addressed by Implementing Solution

PR.DS-5

[110] https://docs.microsoft.com/en-us/windows/desktop/fileio/file-encryption

4.14.4 Architecture Map of Where Solution was Implemented



4.14.5 Installation Instructions and Configurations

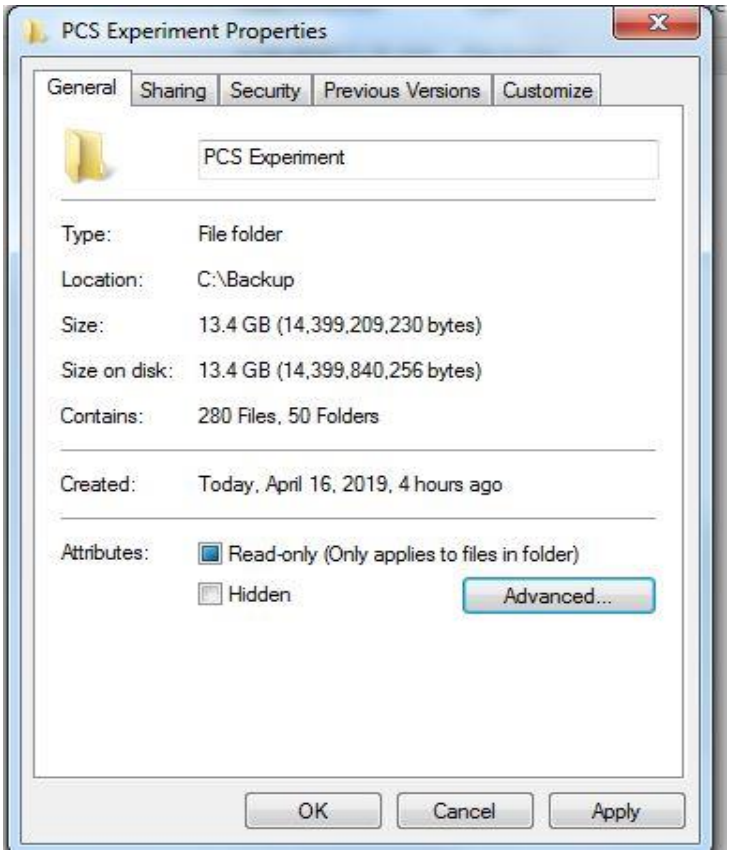
4.14.5.1 Environment Setup

Windows EFS was used to encrypt sensitive folders on the Engineering workstation of the plant.

Hostname	IP Address	OS
Engineering Workstation	172.16.3.10	Windows 7 Professional 64bit

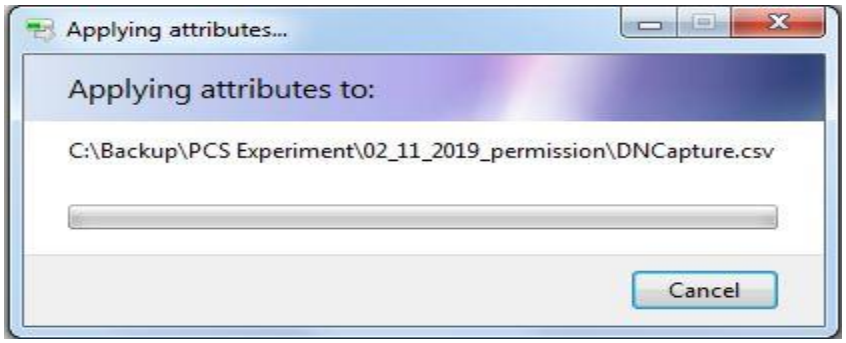
4.14.5.2 Instructions for Encryption

1. Select a parent folder to encrypt. Right Click **Folder Name** > **Properties** > **General Tab** > **Advanced**

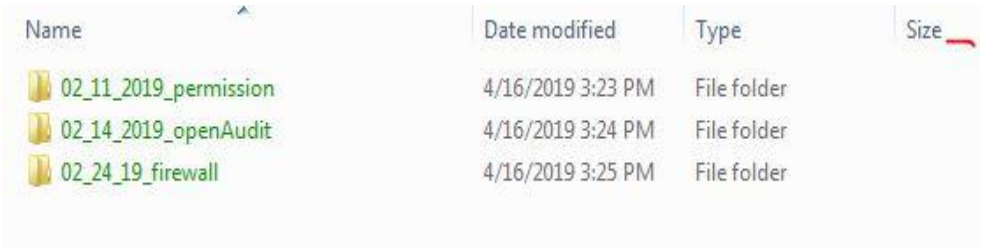


2. Choose the option **Apply changes to folder, subfolders and files**. Click **OK**.

3. Click **Apply**. This will begin the encryption process.



4. Confirm by checking if the folders have turned green upon completion of the encryption as shown below. Any new folder added to this parent folder will be automatically encrypted.

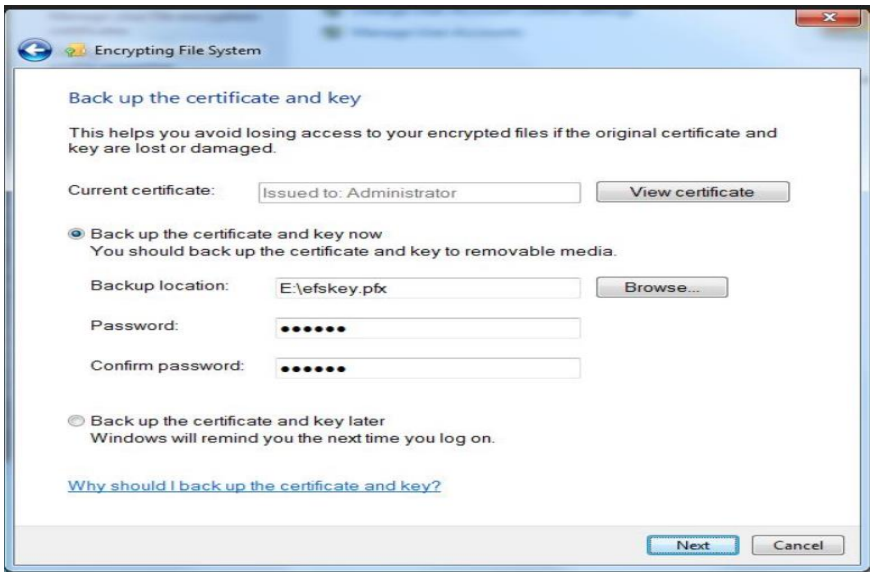


5. Backup the Encryption Key using the following steps,
   a. Double click the pop-up message or alternatively, this process can also be launched manually from **Control Panel** > **All Control Panel Items** > **User Accounts** > **Manage your encryption certificates**
   Note: This process is different for a Windows 10 system.

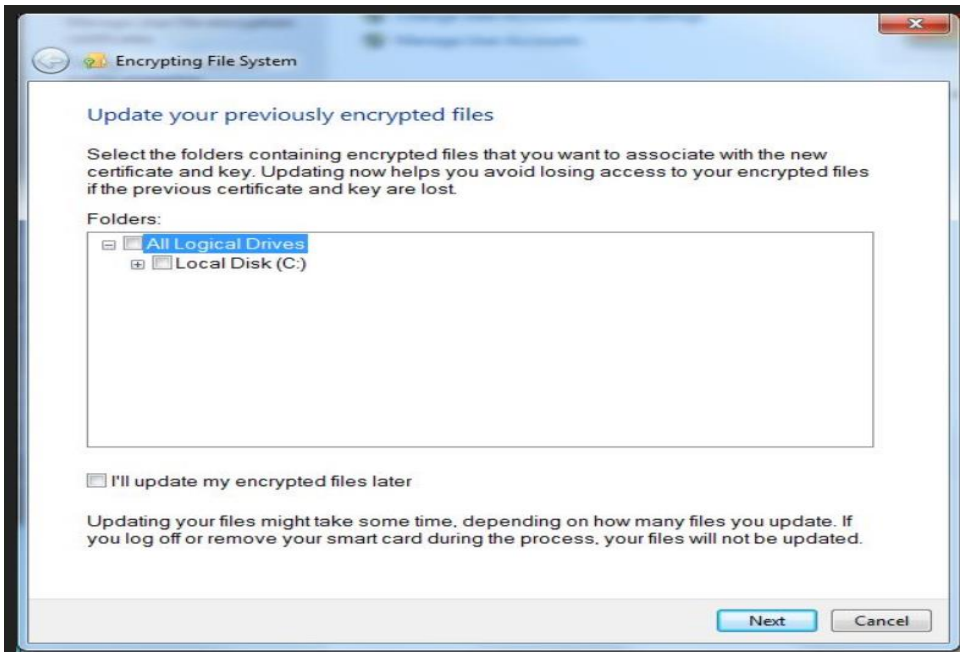
b. Click **Next**

c. Select existing certificate or Create a new one. It is safe to go with the default option

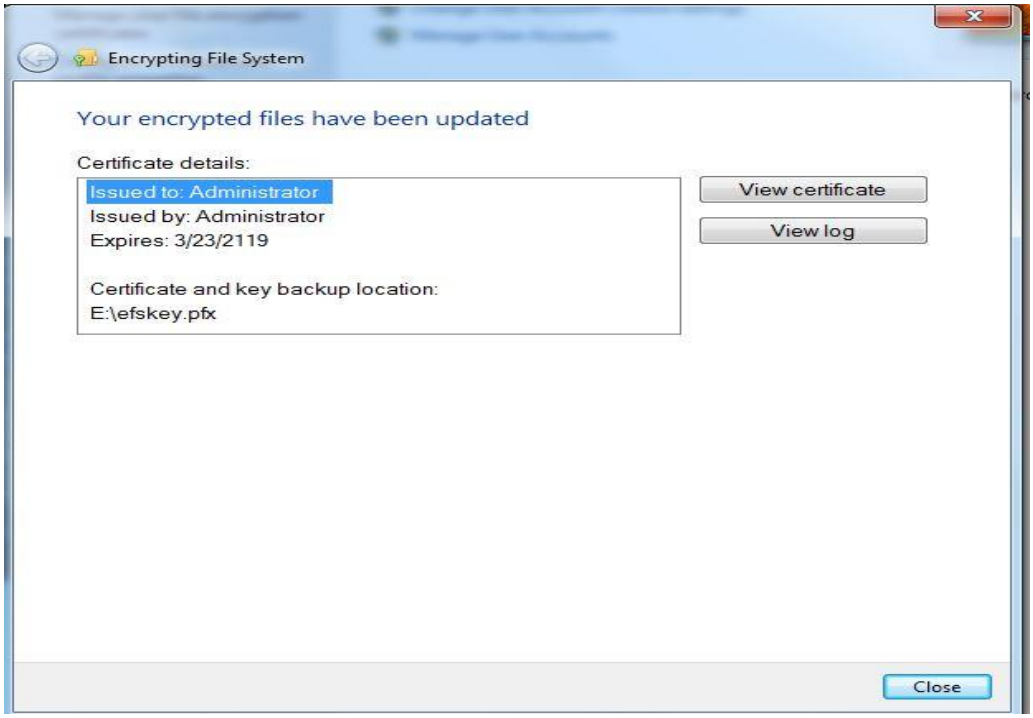
d. Select **Backup the Certificate and Key Now**. Click **Browse** to choose a destination for saving the pfx bundle file. For instance: a USB drive. Enter a password for added protection.



e. Select the appropriate folder to associate with the new certificate and key OR Alternatively select **I'll update my encrypted files later**. Click **Next**



f. A confirmation message as below will be shown next. This completes the backup of the Recovery key



4.14.5.3 Using Encrypted files on a Different Computer

If you want to use your encrypted files on another computer, you need to export the EFS certificate and key from your computer or the USB backup and then import it at the other computer.

4.14.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the Microsoft EFS tool while the manufacturing system was operational:

Experiment PL013.1- Enable file level encryption on HMI host

The FactoryTalk HMI application has a designated file folder to contain the log files for the HMI data. EFS tool was used to encrypt the data log file in this experiment.

There were noticeable performance impacts to the computing resources observed when the EFS was activated for the data log files, especially at the initial operation of the HMI. The processor utilization was noticeable higher from 450 seconds to 750 seconds experiment time and occasionally higher throughout the first 3000 seconds. The disk write operation was significantly higher in the first 800 seconds of the experiment time. The HMI application attempted to access the data log files at the initialization stage and therefore most of the impacts were observed at the beginning of the operation.

On the network side, no significant performance impact was observed. The packet round trip time between the HMI and OPC in both directions reminded mostly constant before and after the EFS was enabled.

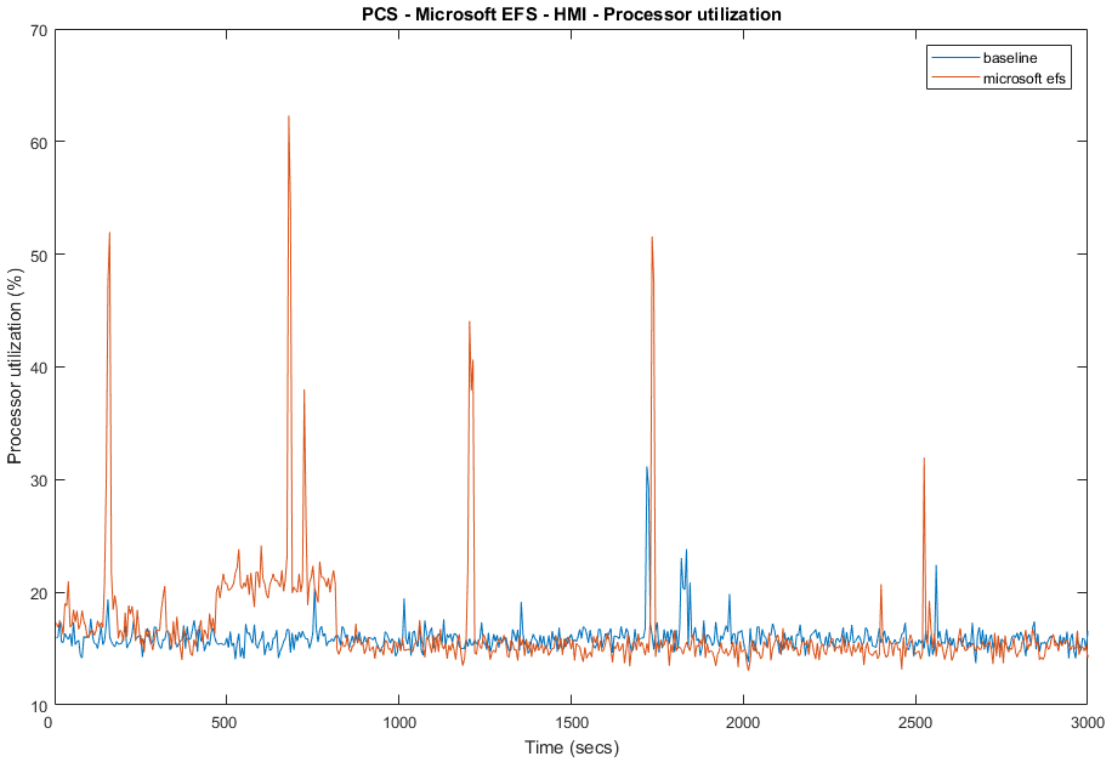


Figure 4-29 HMI computer processor utilization with EFS enable (red) and without EFS enable (blue)

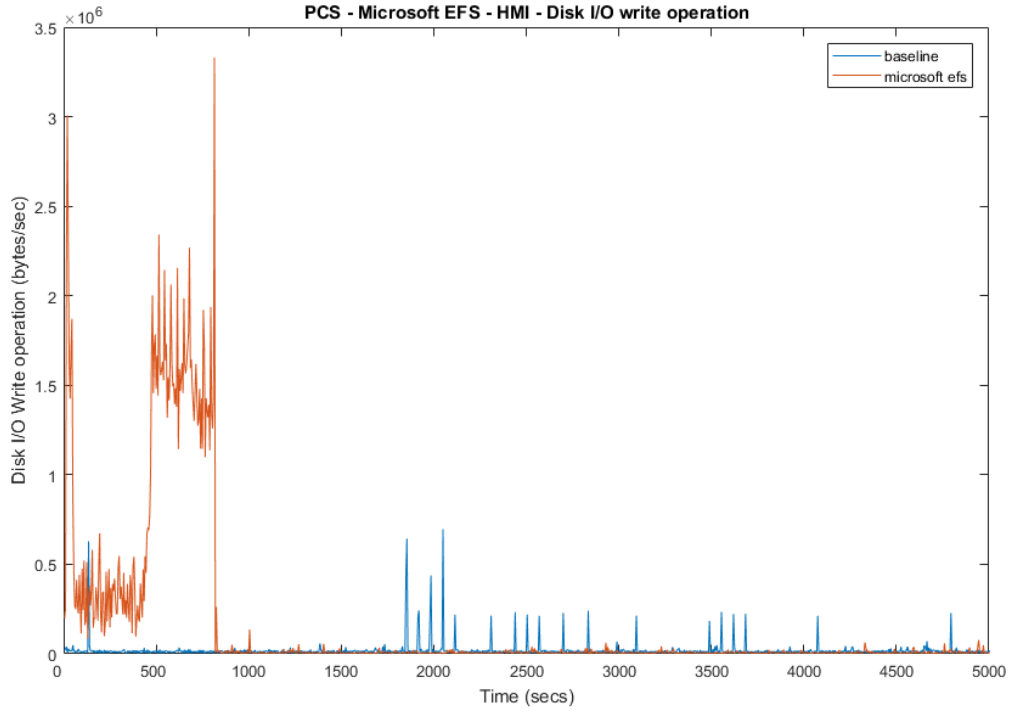


Figure 4-30 HMI computer disk write operation with EFS enable (red) and without EFS enable (blue)

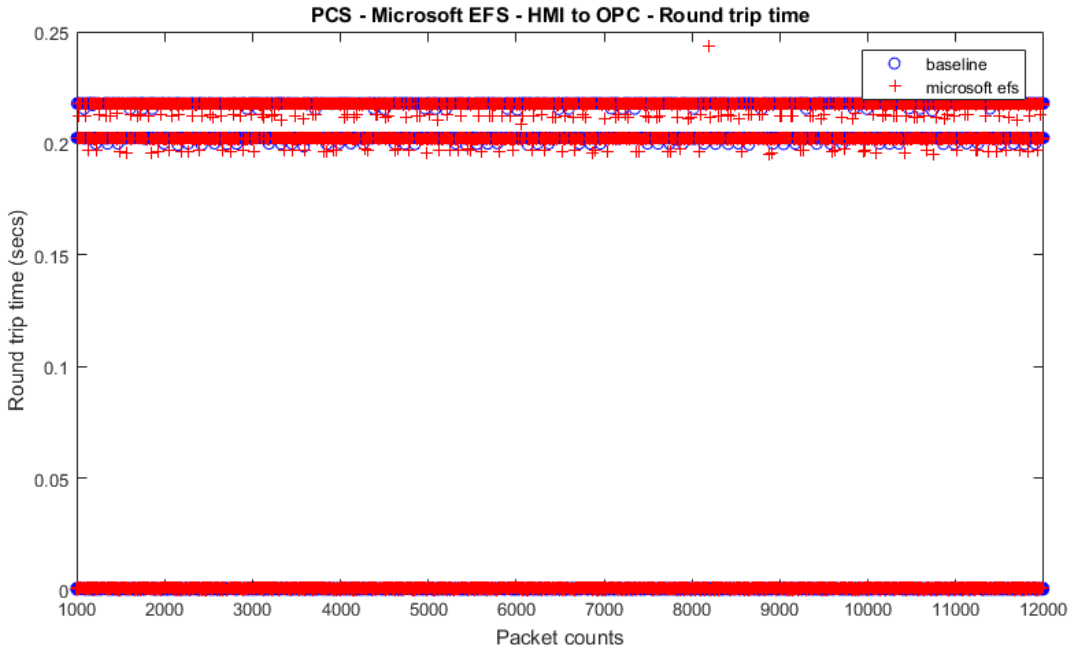


Figure 4-31 Packet round trip time from HMI to OPC with EFS enable (red) and without EFS enable (blue)

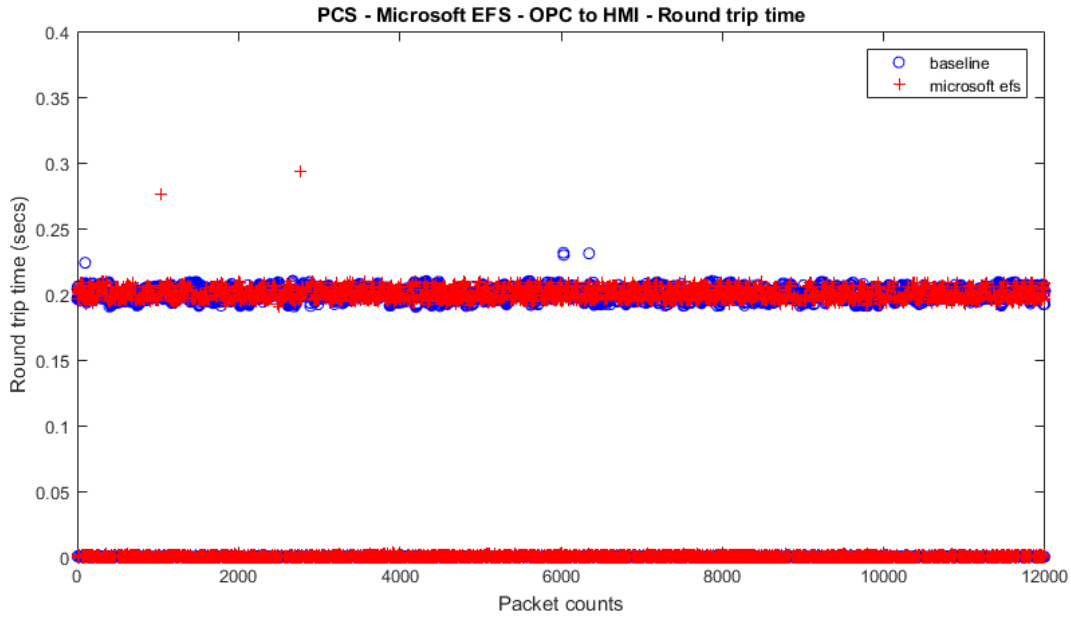


Figure 4-32 Packet round trip time from OPC to HMI with EFS enable (red) and without EFS enable (blue)

The HMI application was not able to access the data log files and new data from operation was not logged. The HMI flagged an error/warning message to the operator.

Care should be taken for encrypting application specific files or folders. There is performance impact to the manufacturing process in the form of losing the ability to log data files in the HMI.

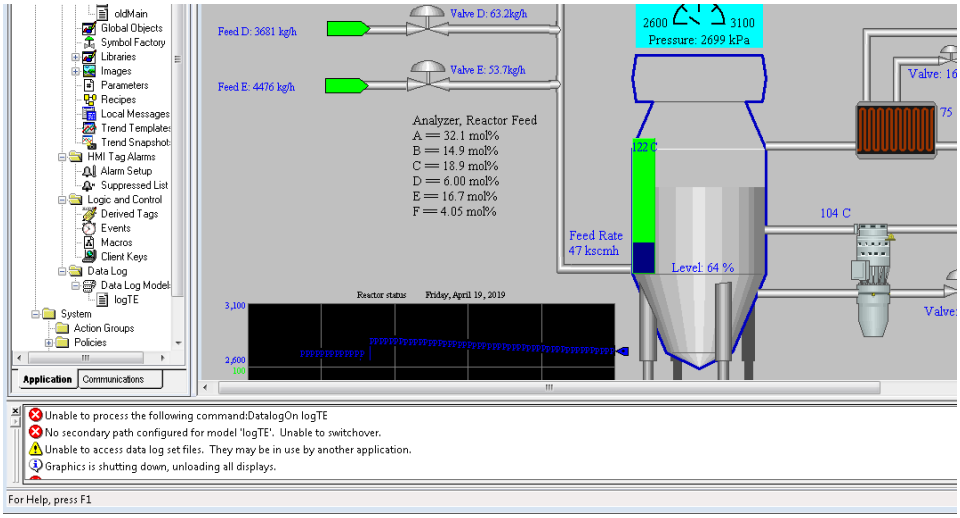


Figure 4-33 HMI screen with warning message "Unable to access data log set files"

4.14.7 Links to Entire Performance Measurement Data Set

- **File Encryption KPI data**
- **File Encryption measurement data**

4.15 GTB Inspector

4.15.1 Technical Solution Overview

GTB Inspector by GTB Technologies is a Data Loss Prevention (DLP) solution that has the ability to detect, log, and block network traffic trying to leave the network. Inspector detects and blocks FTP, Email, HTTP, HTTPS (SSL/TLS), Finger Printed files, USB protection, and other configured exfiltration methods. Inspector is the main component that analyzes all network traffic. GTB Central Console is the device Inspector reports back to. Central Console allows for groups and escalation paths depending on the alerting required.

Points to consider:

- All DLP products have a high cost to implement.
- All DLP products require configuration that can be extensive.

4.15.2 Technical Capabilities Provided by Solution

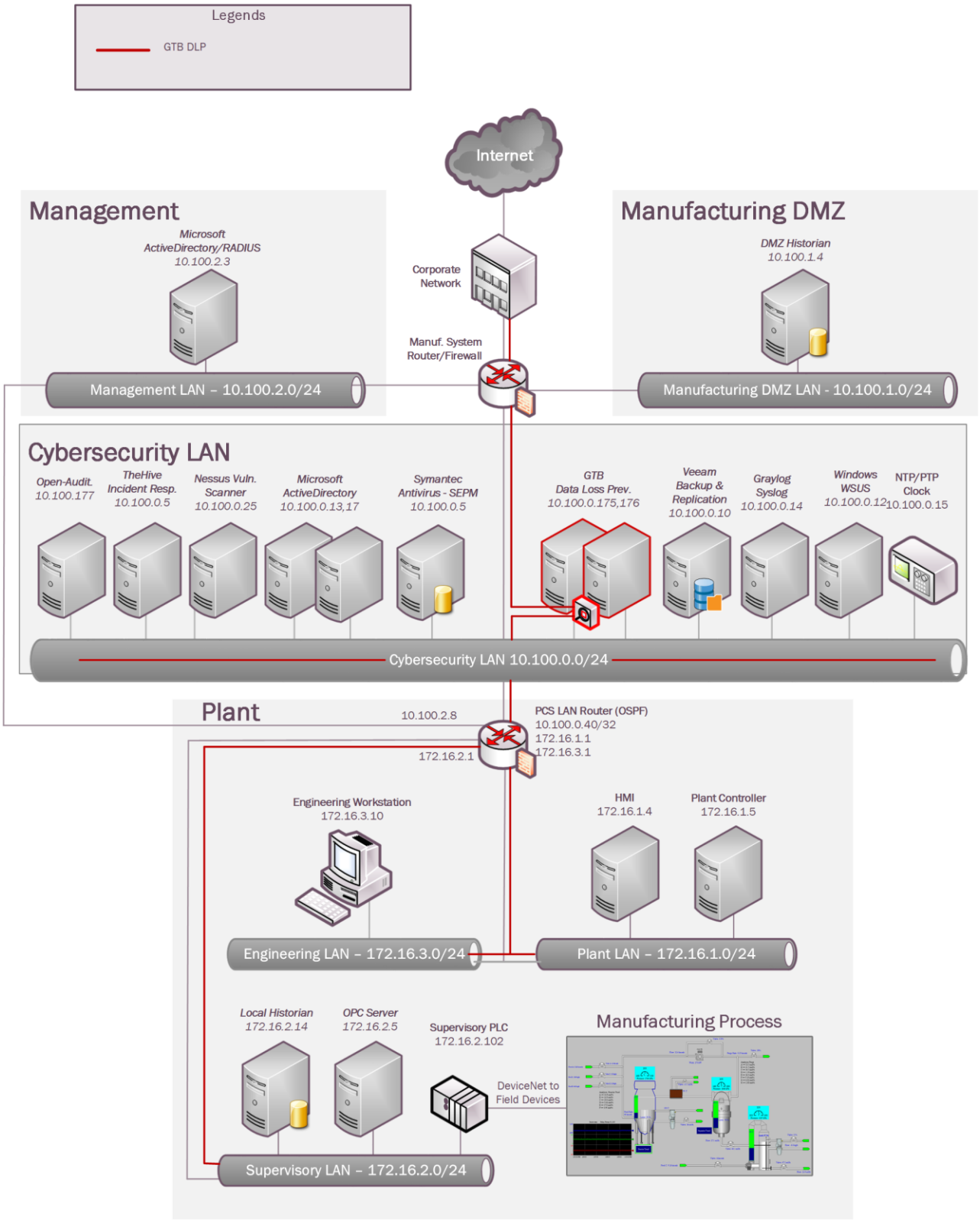
GTB Inspector provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Data Loss Prevention

4.15.3 Subcategories Addressed by Implementing Solution

PR.DS-5

4.15.4 Architecture Map of Where Solution was Implemented



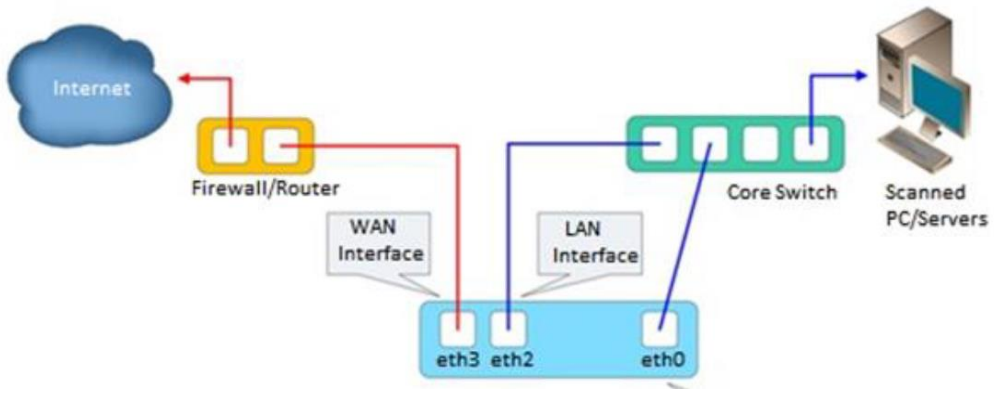
4.15.5 Installation Instructions and Configurations

Details of the solutions implemented:

Name	Version	Purpose	Hardware Details
GTB Inspector	15.6.0	Network DLP	Hyper-V Virtual Machine (Generation 1): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 20 to 30GB (As per the Virtual Appliance file provided by the vendor) • Network: 3 network adapters • OS: CentOS Linux 7 Core
GTB Central Console	15.6.0	Central Reporting and Management for all GTB products	Hyper-V Virtual Machine (Generation 1): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 20 to 30GB (As per the Virtual Appliance file provided by the vendor) • Network: 1 network adapter • OS: CentOS Linux 7 Core

4.15.5.1 Environment Setup

1. Two virtual machines were setup in the Cybersecurity LAN network of the plant, using the ISO image provided by the vendor. Their hardware specifications are described in the table above.
2. The GTB Inspector server was deployed in **Bridge [Inline]** mode as per the official diagram provided by the vendor which is shown below. For additional details, refer to the official install guide.



3. The guest OS networking information on the VM's was set as follows:

```
Virtual Machine: GTB-Inspector
Network interface:eth0
IP address: 10.100.0.175
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
Network interface:eth2->connected to Monitor Port1 of a Network Aggregator device
Network interface:eth3->connected to WAN interface of our Cisco-ASA firewall.

Virtual Machine: GTB-Central
Network interface:eth0
IP address: 10.100.0.176
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

4.15.5.2 Setting up the GTB Central console

1. Download the ISO file of GTB Central Console and install guides[111]
2. Setup the virtual machine by booting off the ISO on your preferred Hypervisor.
3. Perform initial configuration such as creating a DNS record, assigning a Static IP address to the server, etc.
4. Login to the Central Console Web UI using the default credentials. Click **Administration** > **Licensing** to upload the license file. Restart once done.
5. Click **DLP Setup** tab > **Network** to enter the IP address settings.
6. Click **DLP Setup** tab > **LDAP** to configure AD server details.
7. Click **DLP Setup** tab > **Email & Alerts.** to configure smtp server settings.
8. Click **DLP Setup** tab > **Date & Time** > Enter **NTP** Server details.
9. Click **DLP Setup** tab > **SIEM** > Enter the IP address of Syslog / SIEM server

4.15.5.3 Setting up the GTB Inspector

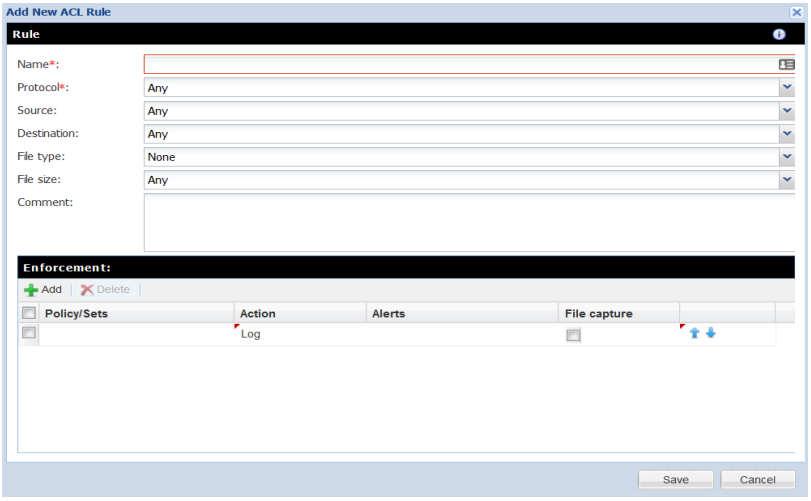
7. Download the ISO file of GTB Inspector and install guides[112]
8. Setup the virtual machine using the ISO files on your preferred Hypervisor.
9. Perform initial configuration such as creating DNS records, assigning Static IP address, setting up the LAN and WAN interfaces for the Inspector server, etc. For detailed instructions, refer to the GTB product install guides.
10. Login to the Inspector server Web UI using the default credentials as provided. Click **Administration** > **Licensing** to upload the license file. Restart once done.
11. Click **Configuration** tab > **Email Alerts.** to configure smtp server settings.

[111] https://gttb.com/downloads/
[112] https://gttb.com/downloads/

12. Click **Configuration** tab > **LDAP Integration**, to configure Active Directory server details.
13. Click **Configuration** tab > **Network** > Set the Deployment Mode as required.
14. Click **Configuration** tab > **SIEM** > Enter the IP address of Syslog / SIEM server.
15. Click **Configuration** tab > **SSL Proxy** > Upload a Public Certificate (if any) for SSL decryption.
16. Click **Configuration** tab > **Central Console** > Enter the hostname of the GTB Central server. Ensure the inspector can reach the Central console.

4.15.5.4 Creating ACL Rules on the Central Console

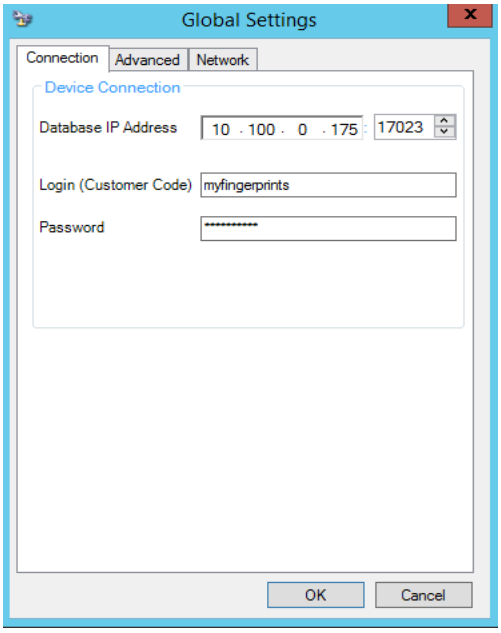
1. Login to the Central Console Web UI. Click **DLP-Setup** > **Network DLP**
2. Click on the <Inspector server name> listed under **Categories**.
3. Click **Add** button. The Add New ACL Rule window should pop-up



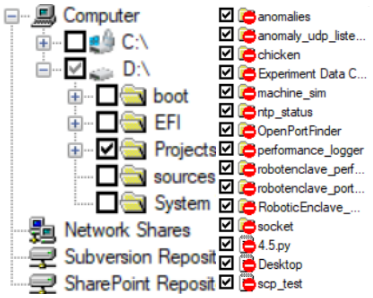
4. Enter the information as required under Name, Protocol, Source, Destination, File Type.
   Selecting **Protocol** = **Any** will enable the Inspector to inspect all protocols.
   Note: This may cause a performance impact depending on the number of clients within your organization.
5. Click **Add** under **Enforcement to** configure Policy/Sets. Select from any of the default policies for Credit Card Numbers (CCN), Social Security etc., or create a new one.
6. Select the action to be taken – Log, Block, S-Block and Pass.
7. Check mark the File Capture option to retain a copy of the offending data.
8. Click **Save**.
9. Click **Deploy-All**. This sends newly created policy to the Inspector.
10. (Optional) Order rules if more than one by clicking the **UP / DOWN** arrows. Rules always work from Top to down.

4.15.5.5 Fingerprint Files using Security Manager

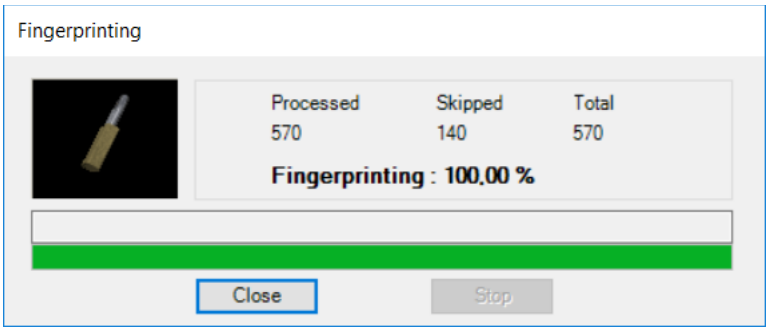
1. Click **Help Tab** on the Central Console. Download **GTB Security Manager** on a Windows system**.**
2. Run the installer (For example *GTBSecurityManager_15.3.0.msi).* Follow the on-screen instructions to complete the install. Reboot the system once done.
3. Launch the GTB Security Manager by doing a **Run as Administrator**.
4. Click **Settings**. Enter the IP address of the Central Console server. The user and password are prepopulated. Click **OK** to save changes.



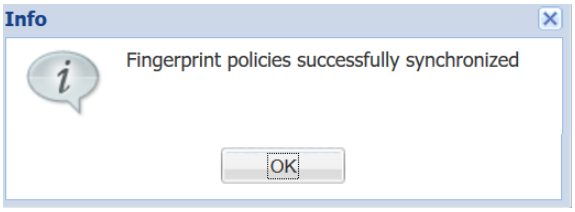
5. Click **File** from the Menu > **New** > **New File Profile.** This will launch a new window with an Explorer like interface allowing to select files/folders for fingerprinting.
6. Select the files or folders that need fingerprinting. Once a folder is selected all files within selected folder will receive a check mark indicating which files will be fingerprinted.



7. Click **Save**. Select a Location to save the newly created profile.
8. Click on the **padlock** icon to start the fingerprinting process.
9. View the Output screen to monitor the progress of Fingerprinting. Once completed, click Close.



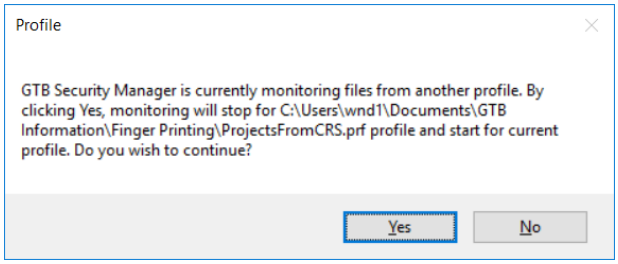
10. Click **View** on the Menu bar > **Profiles** > **Profiles Window >** <*Profile Name*>
11. Select the Profile that was created earlier. Right click > **Start Monitoring.**
    Once monitoring is enabled, files will be listed under **Currently Monitoring** tab.
12. Login back to **Central Console**. Navigate to **Account Manager** Tab and click **Refesh Polices.** Wait for the success prompt.



13. Click **DLP Setup** > **Policy Management** > Double-click **Default** to launch a new Window.
14. Click **Add Policy**.
15. Click the drop-down and select a File.
16. Click **Save** once done. Upon completion, all fingerprinted files from above steps will automatically be added to default Network DLP policy applied ACL. New Default values are **SSN, CCN, and File**

Additional Information on Fingerprinting:

- Fingerprint feature only allows for one active Profile at a time. If another profile is set to **Start Monitoring,** a warning message as shown below will be generated



- Install **GTB Security Manager** on a machine that can be the central repositoiry for all fingerprinted files. Creating a large folder were the files can placed into for fingerprinting. Files need not remain in saved location once the profile has been fingerprinted and uploaded to **Central Console**. Access to fingerprinted files is only required when changes are made to profile containing said files.
- Fingerprinted files follow acl rules created within Central Console. Rules are processed in order from top to bottom. The first rule with a matching violation takes precedence over rules below.

4.15.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the installation of GTB into the PCS due to its location within the network topology. No manufacturing process components across the boundary on a regular basis while the system is operational.

4.15.7 Links to Entire Performance Measurement Data Set

N/A

4.16 Graylog

4.16.1 Technical Solution Overview

Graylog is an open source log management tool. It can collect, parse and enrich logs, wire data, and event data from any data source. Graylog also provides centralized configuration management for 3rd party collectors such as beats, fluentd and nxlog. The processing pipelines allow for greater flexibility in routing, blacklisting, modifying and enriching messages in real-time as they enter Graylog. It has a powerful search syntax to help query exactly what we are looking for. With Graylog one can even create dashboards to visualize metrics and observe trends in one central location.[113]

Points to consider:

- Open source product with good community support
- Easy to setup and customize. Support log collection from any OS platform.
- It is packaged for major Linux distributions, has a VM ready for use and Docker images are also available.
- The dashboard part, even if though well integrated and useful, lacks many features and visualizations contained in other elastic search tools such as Kibana (like aggregations).

4.16.2 Technical Capabilities Provided by Solution

Graylog provides components of the following Technical Capabilities described in Section 6 of Volume 1:

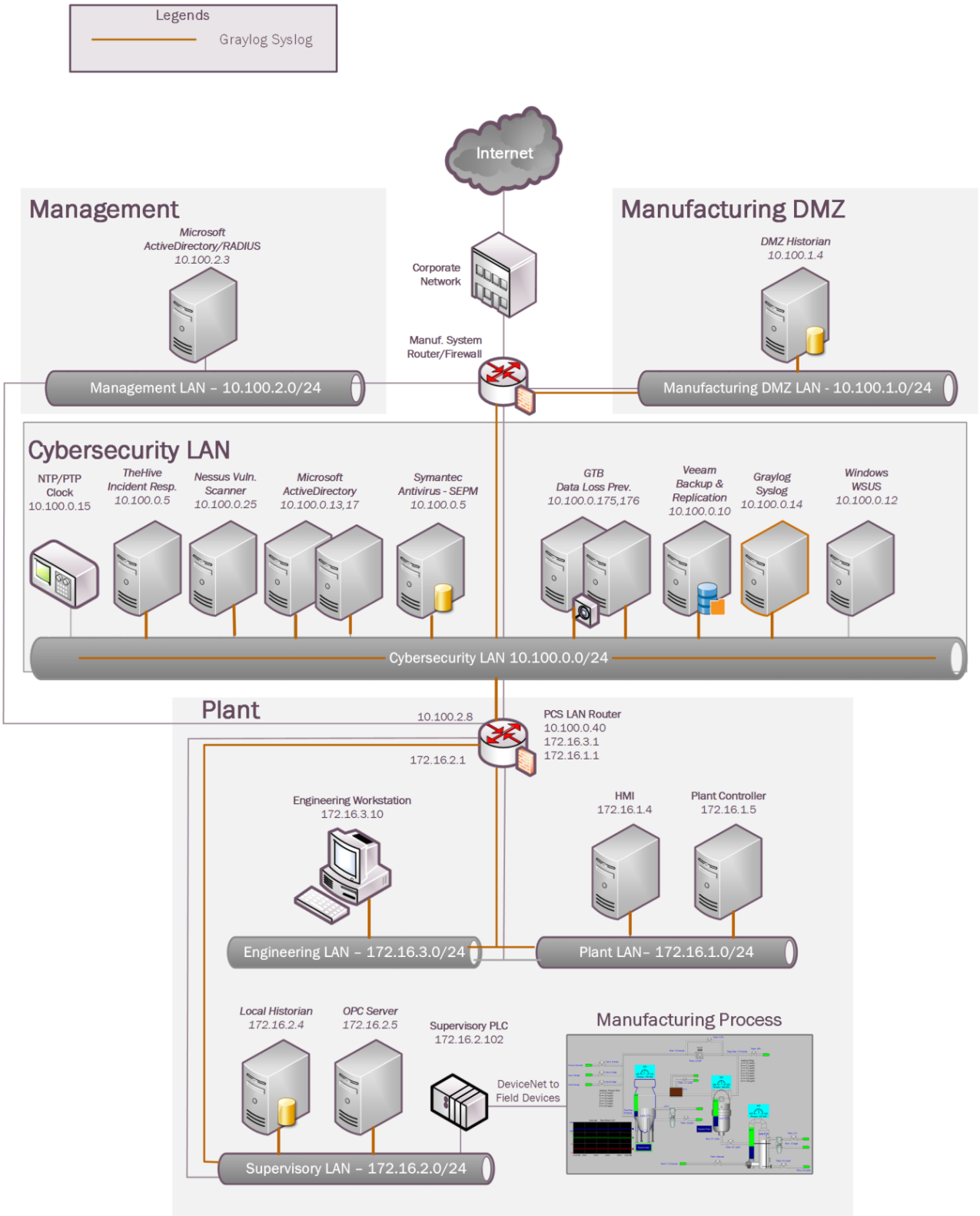
- Network Monitoring
- Event Logging
- Forensics

4.16.3 Subcategories Addressed by Implementing Solution

PR.DS-5, PR.MA-2, PR.PT-1, PR.PT-4, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-6, DE.CM-7, DE.DP-3, RS.AN-3

[113] http://docs.graylog.org/en/3.0/

4.16.4 Architecture Map of Where Solution was Implemented



4.16.5 Installation Instructions and Configurations

Details of the solution implemented:

Name	Version	Hardware Details
Graylog Enterprise	2.4.6	Hyper-V Virtual Machine (Generation 1): • Processors: 2 virtual cores • Memory: 6 GB • Disk space: 400 GB Total (i) Root volume as allocated by the Virtual Appliance file provided by the vendor. (ii) 350+ GB Data volume for log storage • Network: 1 network adapter • OS: Ubuntu 14

4.16.5.1 Environment Setup

1. A preconfigured virtual machine (.ova) provided by the vendor was setup on a Hyper-V host server of the Cybersecurity LAN network of the plant with hardware specifications as described in the table above.
2. The guest OS IP information of this server was set as follows:

```
IP address: 10.100.0.14
Gateway: 10.100.0.1
Subnet Mask: 255.255.255.0
DNS:10.100.0.17
```

3. UDP ports 514, 5415 and 1202 were opened on the firewall as required by Graylog to collect syslog messages from the clients. For more information, visit http://docs.graylog.org/en/3.0/

4.16.5.2 Initial Setup

1. Download the installation package as per the Operating system from the Graylog website.[114]
   Note: Graylog provides a preconfigured VM for use in test/training environments.
2. Assign a static IP address to the Linux system (if not already).
3. Install the package using the instructions mentioned in the Graylog documentation.[115]
4. Login to the Web Interface using the default credentials and change the admin password.
5. Configure Active Directory integration as follows
   a. Click on **System** > **Authentication** on the Top menu.

[114] https://www.graylog.org
[115] http://docs.graylog.org/en/3.0/pages/installation/operating_system_packages.html

b. Click on **LDAP / Active Directory** on the Authentication Management page and enter the AD server details**.** Refer to the Graylog docs for detailed instructions.
c. Click on **LDAP Group Mapping** to configure **Group Mapping** options to control the type of access to be assigned to the users. Change the Default User Role depending on your requirement.

4.16.5.3 Receiving Syslog from Windows Servers

NXlog[116] was used as the log shipping utility to forward events from all Windows systems of the plant to our Graylog server. The community edition of NXlog is free to use.

1. Download and install NXlog on the Windows hosts in question.
2. Edit the *nxlog.conf* file located at *C:\Program Files (x86)\nxlog\conf* directory as per whichever category of events you would like to forward to your Graylog server.[117]

For reference, the following event IDs were configured for forwarding from the Engineering Workstation of the plant:

- Event ID 1074 from **System** category to notify us when system gets rebooted
- Event ID 1034 from **Application** category
- Event ID 4625 from **Security** category
- Event ID 4689 from **Security** category and **ProcessName**=*C:\Program Files\..\Rockwell\Rsvsc.host.exe* to notify us when the process for Rockwell Automation software stops.
- All events [*] from *Microsoft-Windows-TerminalServices-LocalSessionManager* category to notify us when a user logs in or logs out of the system.
- Event ID 190 from **Veeam** category to notify us for backup completion messages
- Event ID 1001 from **FTDiag** category which is a custom event ID generated by Factory Talk Administration Software where there is an authentication failure.

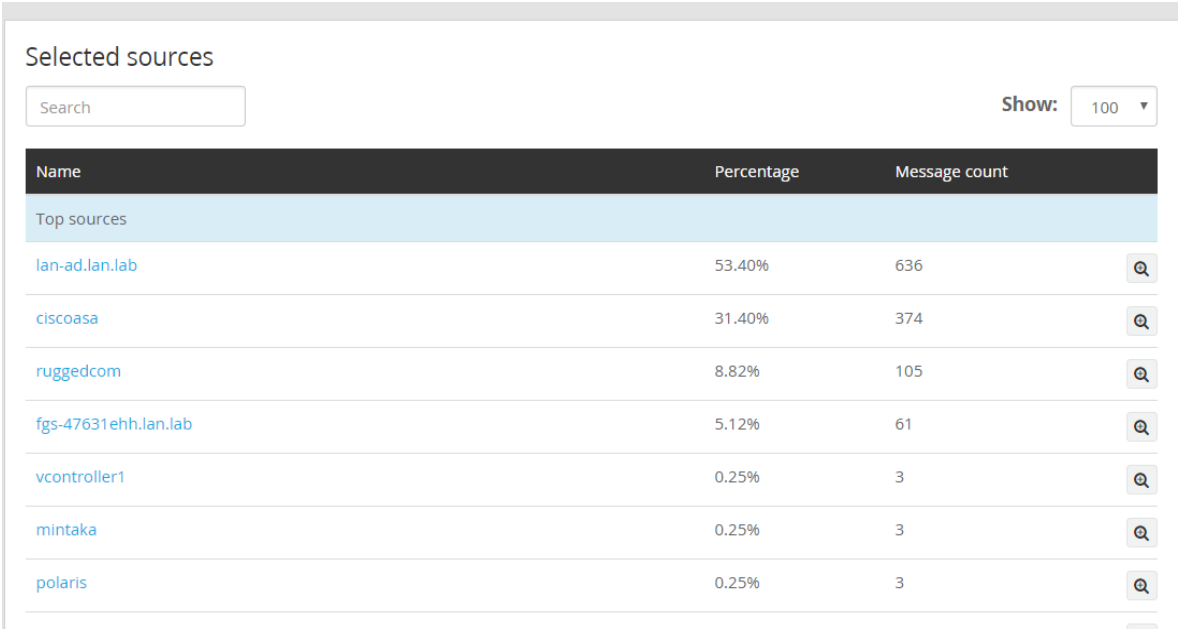
[116] https://nxlog.co/
[117] https://nxlog.co/documentation/nxlog-user-guide/

The figure below shows the nxlog.conf file with the above configuration.

```
## Please set the ROOT to the folder your nxlog was installed into,
## otherwise it will not start.

#define ROOT C:\Program Files\nxlog
define ROOT C:\Program Files (x86)\nxlog

Moduledir %ROOT%\modules
CacheDir %ROOT%\data
Pidfile %ROOT%\data\nxlog.pid
SpoolDir %ROOT%\data
LogFile %ROOT%\data\nxlog.log

<Extension _syslog>
  Module     xm_syslog
</Extension>

<Input in>
Module     im_msvistalog
ReadFromLast True
Query  <QueryList>\
        <Query Id="0">\
        <Select Path="System">*[System[(EventID=1074)]]</Select>\
  <Select Path="Application">*[System[(EventID=1034)]]</Select>\
        <Select Path="Security">*[System[(EventID=4625)]]</Select>\
        <Select Path="Security">*[System[(EventID=4689)] and
EventData[Data[@Name='ProcessName'] and (Data='C:\Program Files (x86)\Common
Files\Rockwell\RsvcHost.exe')]]</Select>\
        <Select Path='Microsoft-Windows-TerminalServices-
LocalSessionManager/Operational'>*</Select>\
  <Select Path="Veeam Agent">*[System[(EventID=190)]]</Select>\
        <Select Path="FTDiag">*[System[(EventID=1001)]]</Select>\
   </Query>\
    </QueryList>
</Input>

<Output out>
  Module     om_udp
  Host       10.100.0.14
  Port       514
  Exec       to_syslog_bsd();
</Output>
<Route 1>
  Path       in => out
```

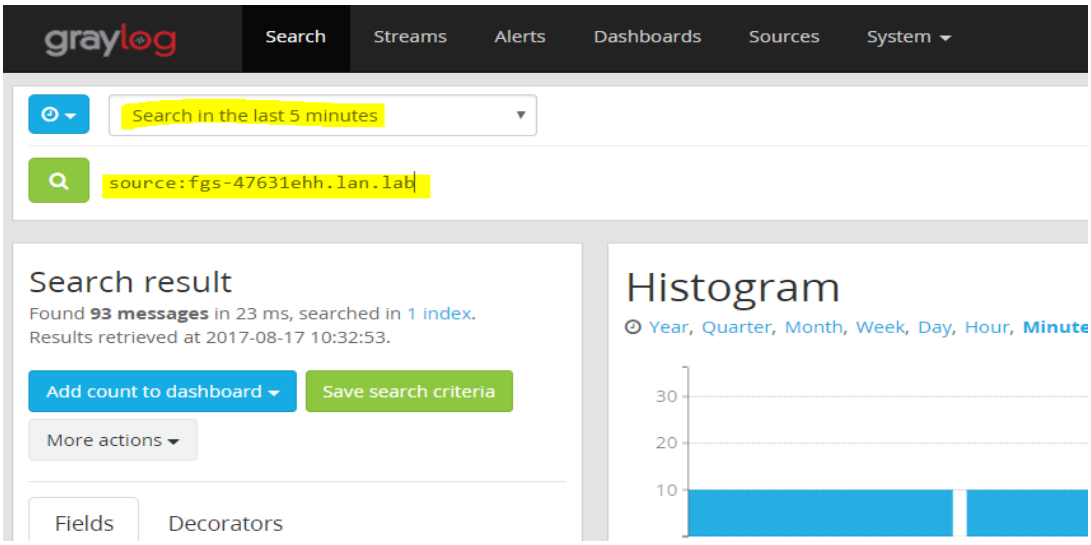
3. Save *nxlog.conf* and restart the NXLOG windows service. The device will now begin sending syslog (events) to the Graylog server. If the service fails to start, check the syntax of your *nxlog.conf* file for any blank spaces or missing parenthesis. Nxlog.conf file is very sensitive to proper indentation.

4. Login to Graylog Web UI. Look for the events from these windows hosts. Click on **Sources** in the Top menu bar to verify if the windows host shows up under the list of **Selected sources.**



5. Search for events from a host by entering a search query and selecting the appropriate time interval in the home page.

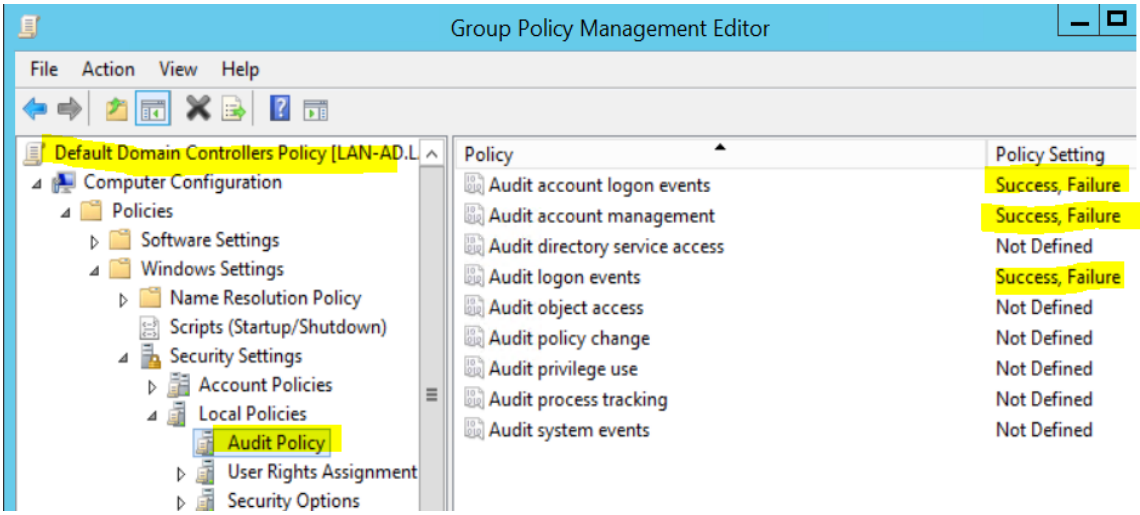
For instance: To search for events by hostname, enter `source: <windows hostname>` in the Search *box* as shown below.



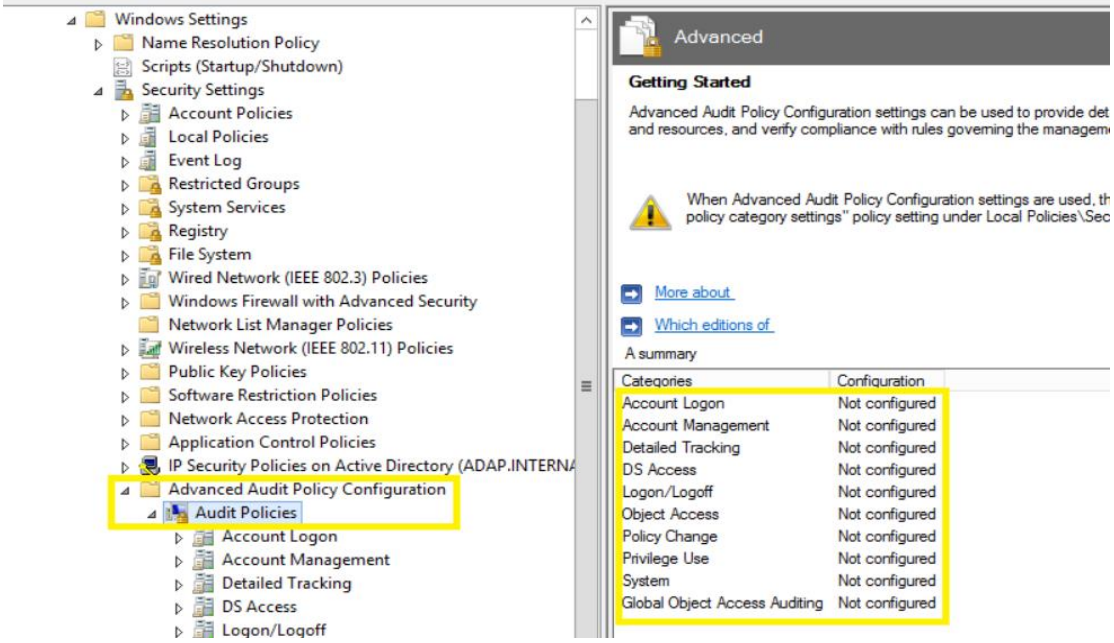
4.16.5.4 Syslog Configuration for Active Directory Domain Controllers

1. Enable Auditing on the Domain Controllers as follows:

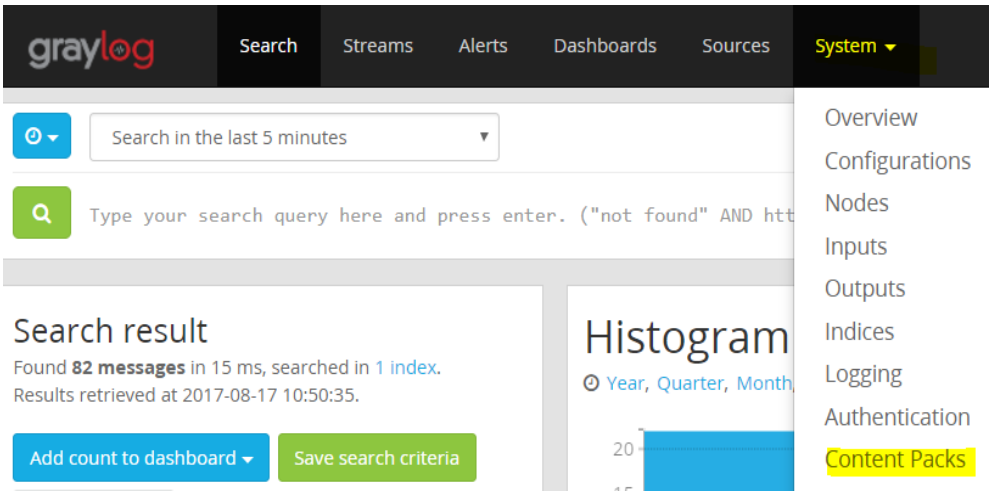
   a. Open **Group Policy Management Console** on the DC.
   b. Edit the **Default Domain Controllers Policy** or Create a new GPO and link to the Domain Controllers OU.
   c. Expand **Computer Configuration > Policies > Windows Settings > Security Settings** > **Local Policies**. Pick or click on the **policies** you would like to audit on one at a time and enable Policy settings of **Success/Failure**.
   For reference, below is a snippet of our Default DC Policy with auditing enabled.



   d. (Optional) Use **Advanced Audit Policies** if desired **in place** of the regular Audit Policy mentioned in Step C to have more granular control on the Categories to audit.

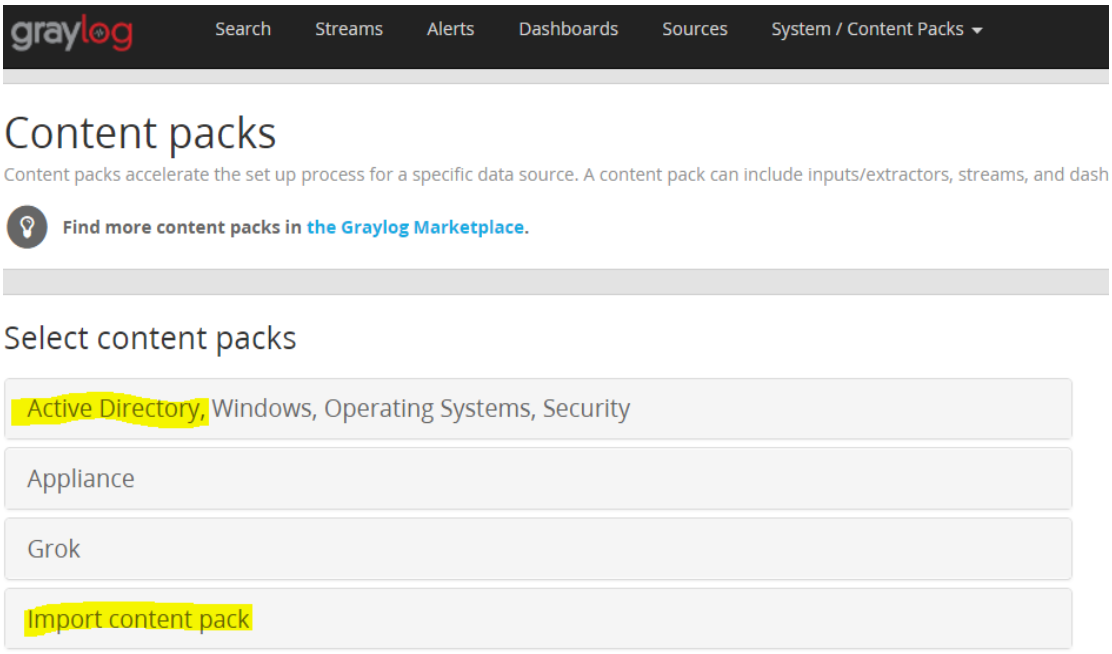


2. Edit the *nxlog.conf* file on the domain controllers to forward events from the Security Category. Filter the Event IDs as required. Restart the nxlog service.
3. Install the Active Directory Content Pack as follows:
   a. Download the AD Content Pack from Graylog marketplace[118]
   b. Permit traffic on **UDP port 5414** on the Graylog server as well in the Network Firewall as required by this AD Content Pack.
   c. Login to the Graylog Web UI. Click on **System > Content Packs**

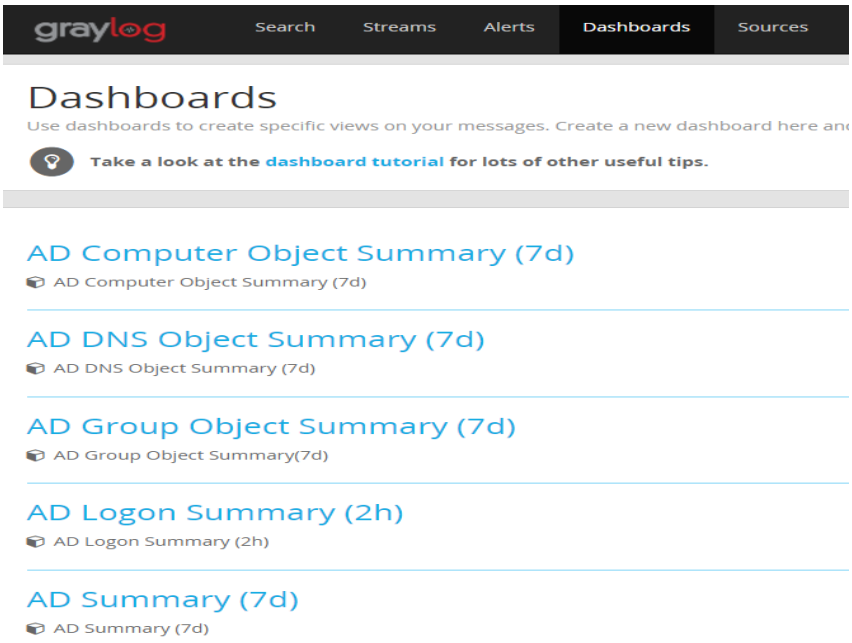


   d. Click on I**mport content packs** to import it. Once import is completed you should see **Active Directory** under **Select Content packs**. This is the pack we just imported.

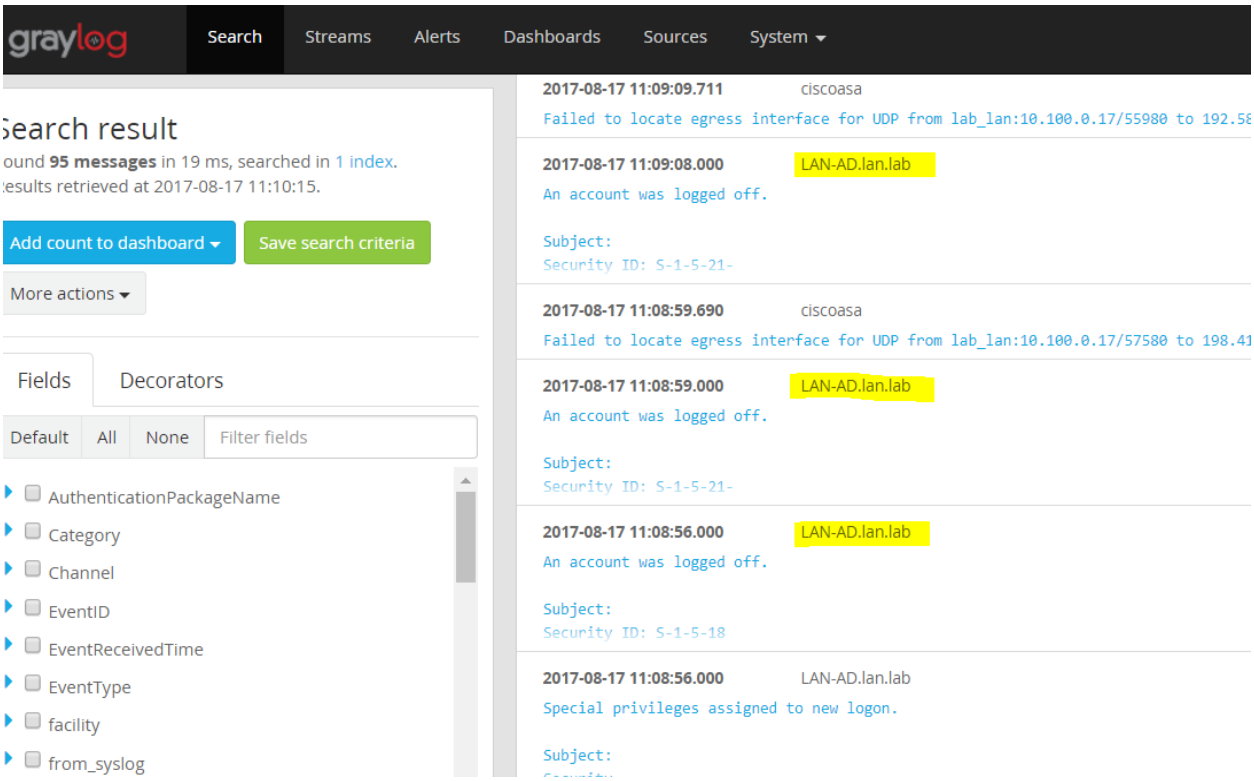
[118] https://marketplace.graylog.org/addons/750b88ea-67f7-47b1-9a6c-cbbc828d9e25



e. Click on **Dashboards** to view the new graphs of the AD user and group activities. The graphs will begin populating data assuming the AD server is successfully sending over the events to Graylog server.



f. Look for events from the AD server on the main dashboard. Use the search query as explained in previous steps to look for events using the server hostname.



4.16.5.5 Receiving Syslog from Boundary Firewall/Network Devices

1. Login to Network switch/router either via Web UI or CLI.
2. (If using Web UI) Look for the option of Syslog or Monitoring in the Menu.
3. Enter the IP address of Graylog server. Save the settings.
4. (If using CLI) Refer to the vendor documentation for enabling logging.

For reference, shown below are commands that were run on the Allen Bradley Stratix Boundary Router to forward syslog to the IP address of our Graylog server.

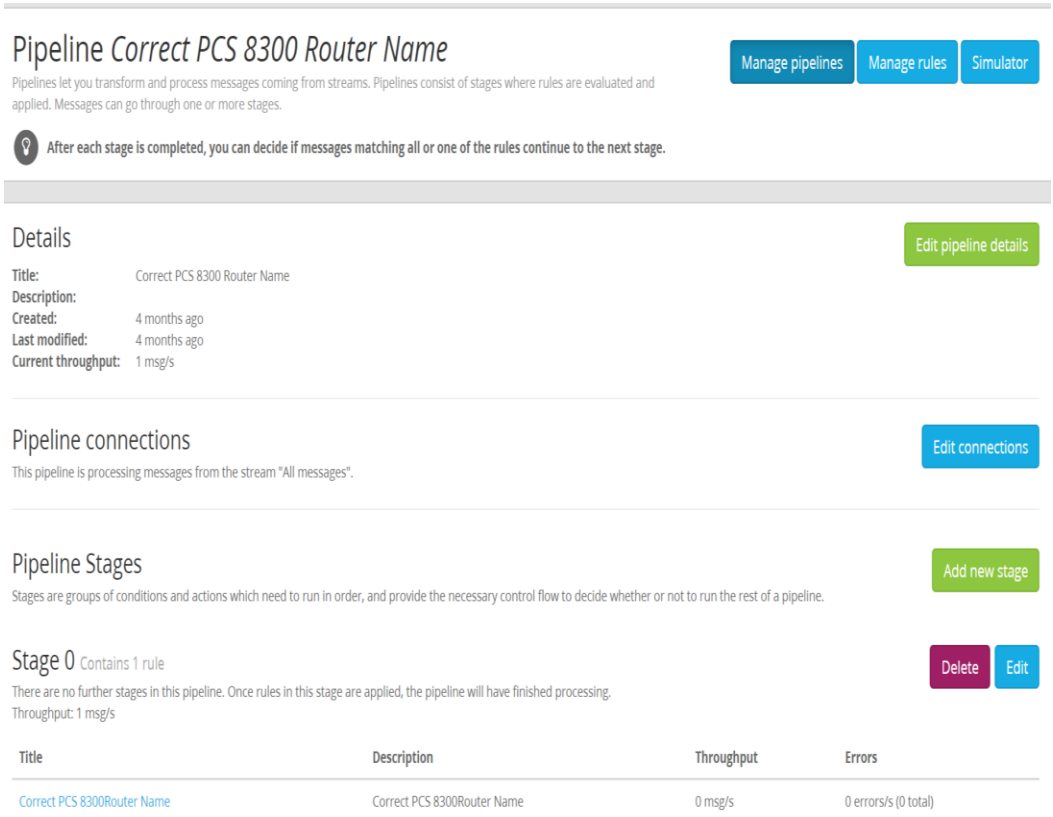
```
#enable
#configure terminal
(config)#logging enable
(config)#logging 10.100.0.14
(config)#logging trap informational
(config)#end
#wr mem
```

4.16.5.6 Configuring Pipelines/Rules

It was observed that messages from Network devices ended up in Graylog under the device's **IP address** as the **Source** instead of its hostname. This an expected behavior as different vendor devices log in different formats. To overcome this, Graylog offers native features such as Pipelines, Rules, Grok Patterns and Lookup Tables to get around this.[119]

1. Click on **System > Pipelines** option in the TOP Menu bar
2. Click on **Add new pipeline** to create one.
3. Click on **Manage Rules** button for Rules
4. Click on **Create rule** to create a rule to associate with a pipeline.

The following image shows the details of one such pipeline **Correct PCS 8300 Router** Name and its corresponding rule **Correct PCS 8300 Router Name** that was created to make the Allen Bradley Boundary Router display its hostname correctly in the search results.

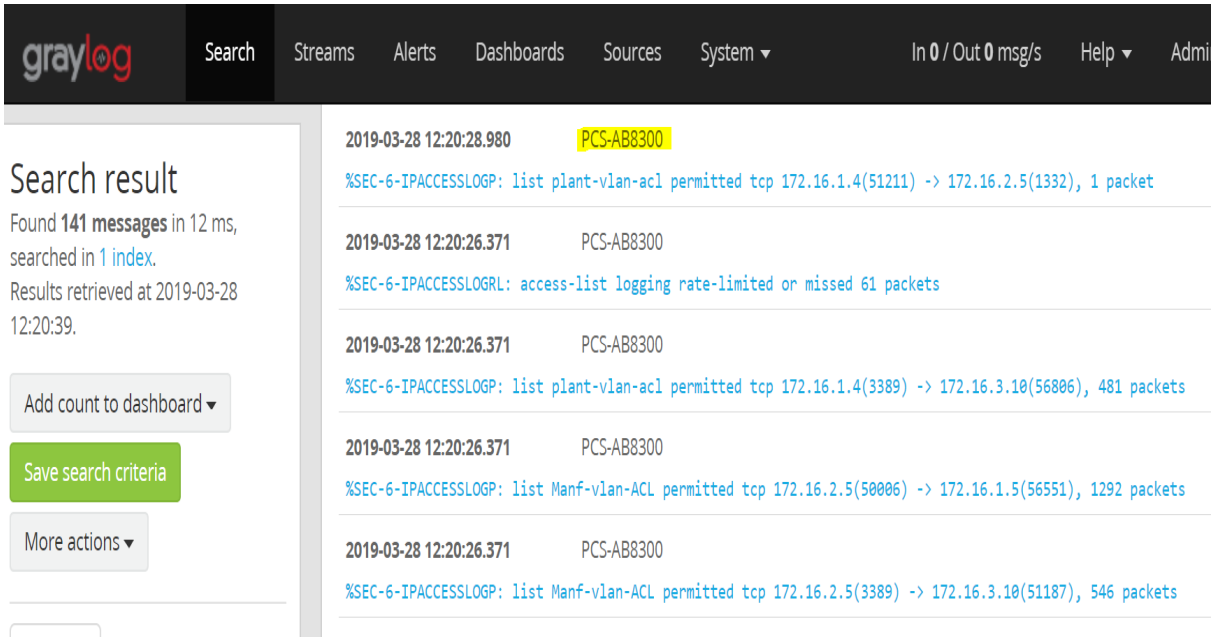


[119] http://docs.graylog.org/en/2.4/pages/pipelines.html

Rule source

```
rule "Correct PCS 8300Router Name"
when
  has_field("source") AND contains(to_string($message.source), "10.100.0.40")
then
   set_field("source", "PCS-AB8300");
end
```

The result in the **Search** pane now shows the hostname **PCS-AB8300** as configured in the Rule.



4.16.5.7 Configuring Email Notifications for Alert conditions

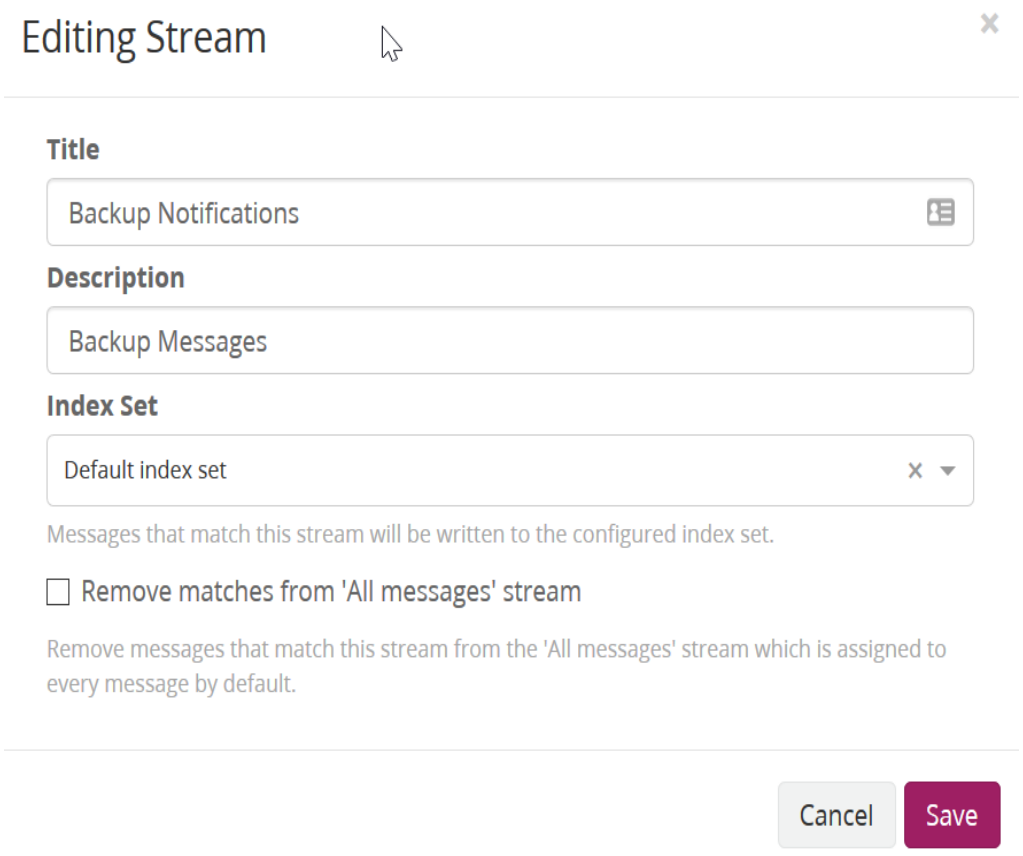
Email alerts for any custom events, alert conditions can be setup. The process below shows how our Graylog was configured to send out email notifications for any events related to **Veeam Backups** that were received from the Windows clients.

Follow this process to define your custom alert conditions.

There are three configuration settings required for email notification to work:

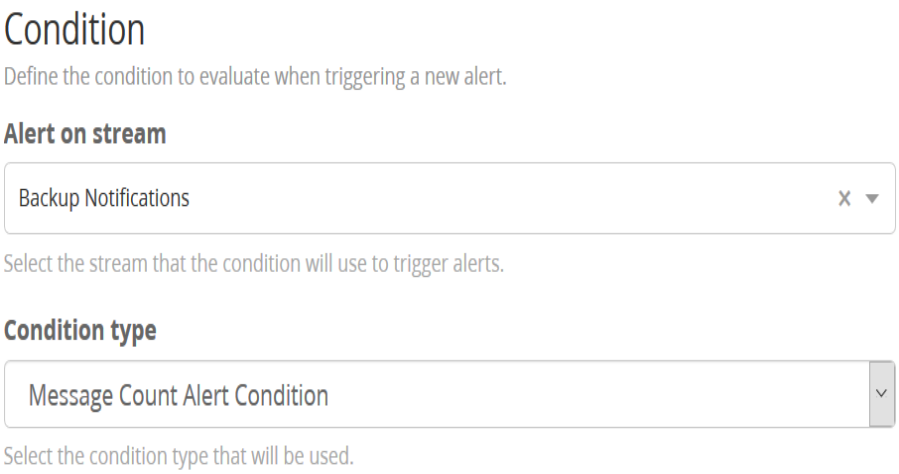
- Creating a **stream.**
- Adding an **alert condition.**
- Creating a **notification**.

1. Click on **Streams** on the **Top-Menu** > **Create a Stream >** Enter **Title, Description,** and **Index Set** which should default to **Default index set**
2. Click **Save** to save the changes

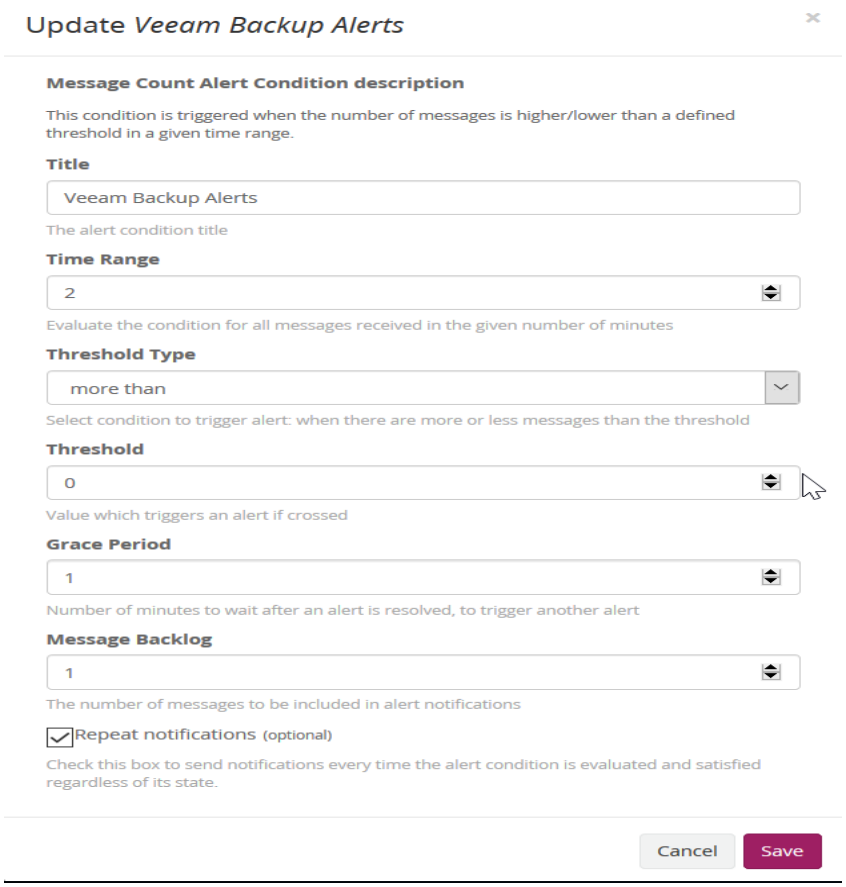


3. Click on **Alerts** in the Top menu > **Manage conditions** > **Add New Condition** to define a condition.

4. Click the **Drop menu** under **Alert on Stream** and select the stream created earlier. Under **Condition Type**, select **Message Count Alert Condition.**



5. Click **Add Alert Condition**. Fill out the required information in the window.
6. Click **Save** to complete (See below for example of current Message Count Alert Condition).



7. Create a notification as follows:

    a. Click on **Manage notifications** in upper right-hand corner.
    b. Click **Add New Notification**
    c. Select notification created earlier from the drop-down menu under Notify on Stream**.**
    d. Select **Email Alert Callback** under Notification Type
    e. Click **Add alert notification** button
    f. Title: < Some text> For instance: **Veeam Backup Alerts**
    g. (For Reference) Email Subject: "Successful Veeam Backup source: ${foreach backlog message}${message.source}${end}" without the quotes, see below for screen shot of current callback wording.
    h. **Sende**r: < sender address >
    i. **E-mail Body**:

```
Alert Description: ${check_result.resultDescription}
Date: ${check_result.triggeredAt}
Stream ID: ${stream.id}
Stream title: ${stream.title}
Stream description: ${stream.description}
Alert Condition Title: ${alertCondition.title}

${if backlog}Last messages accounting for this alert:
${foreach backlog message}${message}

${end}${else}<No backlog>
${end}
```

    j. **User Receivers**: Select a Graylog user if desired
    k. **Email Receivers**: Enter email address for individuals receiving these alerts
    l. Click **Save**

8. Test new Streams / Alerts / Notifications to ensure they are configured correctly.

4.16.5.8 Additional Information

- There are many useful Content packs and plugins available[120] as per vendor specific technologies, devices such as Cisco, Microsoft DNS, Bro IDS, Cacti, Symantec etc.
- Additional guidance is available on creating pipelines.[121]

[120] https://marketplace.graylog.org
[121] https://jalogisch.de/2018/working-with-cisco-asa-nexus-on-graylog/

Lessons Learned

Carefully configure the level of logging on each system. In case of Windows clients, filter out Event IDs in the *nxlog.conf* instead of enabling every event category, as this can generate a high volume of events which in turn will impact search operations in Graylog and overall performance of the Graylog server. When using Group Policy to enable auditing, select only the categories which are required**.** Some categories such as Process Creation generate tremendous amounts of noise.

4.16.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the use of the Graylog due to its typical installation and usage location (i.e., external to the manufacturing system).

4.16.7 Links to Entire Performance Measurement Data Set

N/A

4.17 DBAN

4.17.1 Technical Solution Overview

DBAN is a free open source data wiping utility allowing the ability to sanitize hard drives to ensure data is not left behind when drives are beginning decommissioned and prepared for removal from on-premise. DBAN and other hard drive sanitization tools only work with spinning hard drives, SSD hard drives and other flash media refer to vendors for specific directions for sanitizing media before removing from company control.

4.17.2 Technical Capabilities Provided by Solution

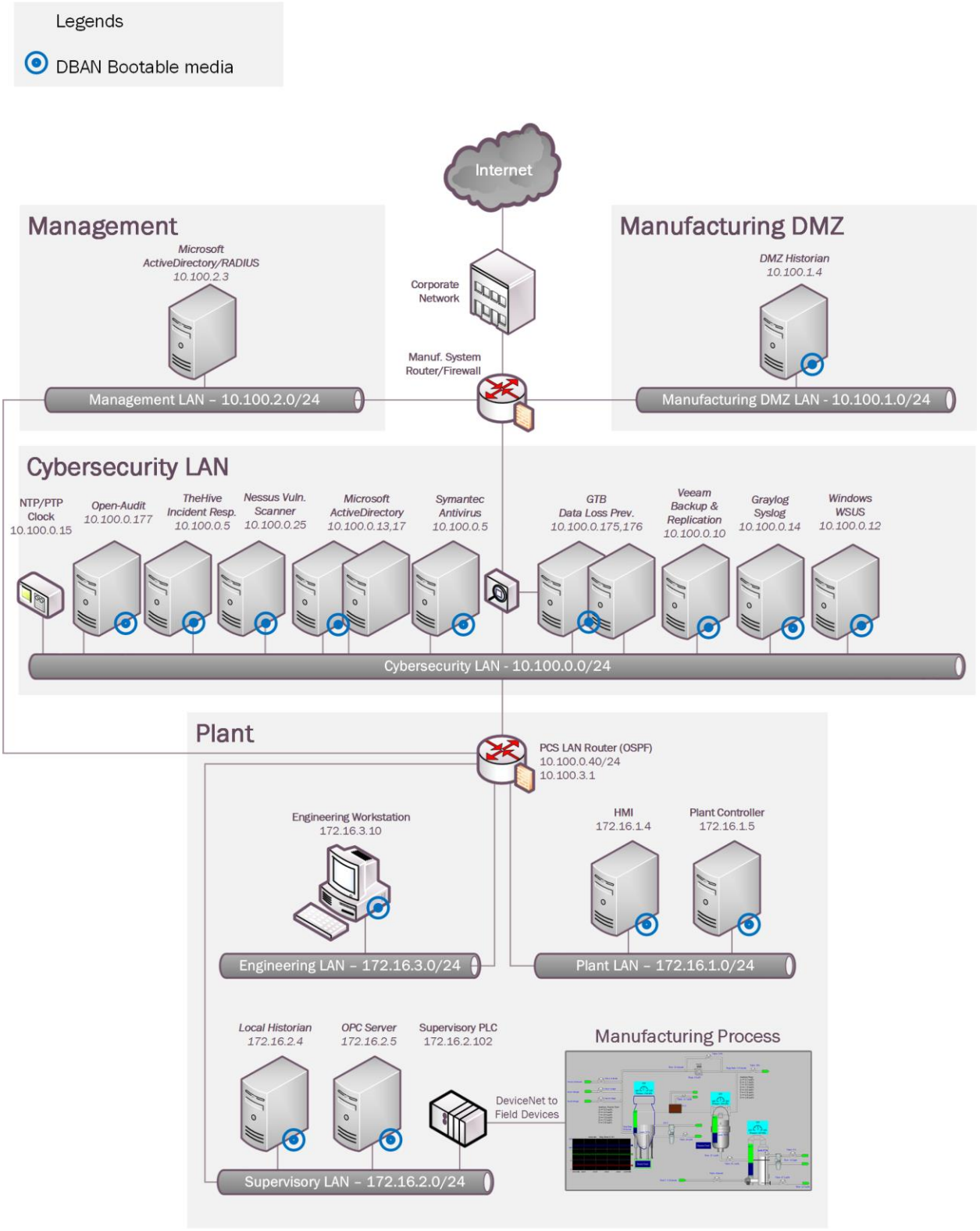
DBAN provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Media Sanitization

4.17.3 Subcategories Addressed by Implementing Solution

PR.DS-3, PR.IP-6

4.17.4 Architecture Map of Where Solution was Implemented



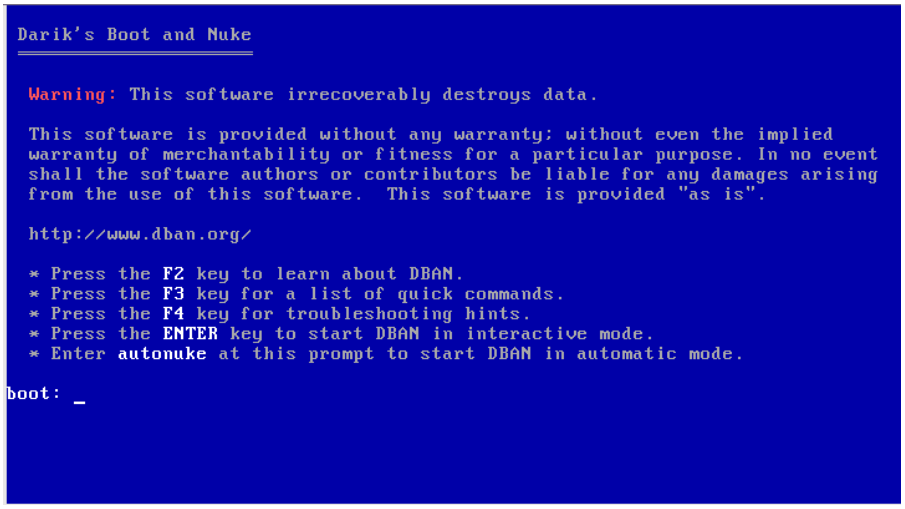
4.17.5 Installation Instructions and Configurations

4.17.5.1 Setup

1. Download the DBAN ISO file[122]
2. Burn to a CD/DVD, or USB drive using any of the available ISO bootable utilities.

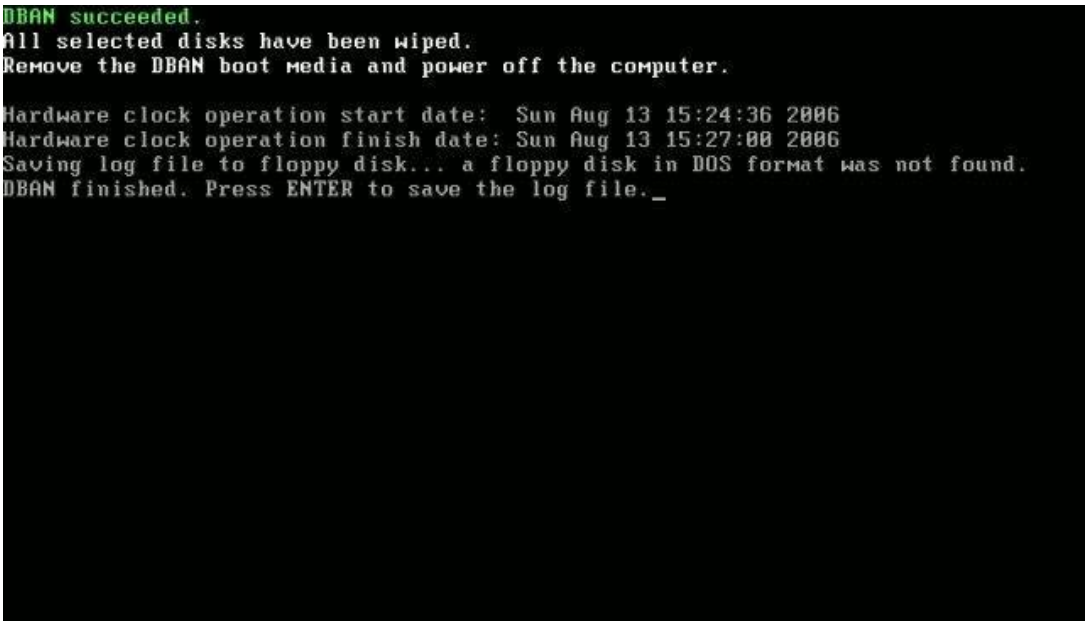
4.17.5.2 Instructions

1. Boot up the computer requiring sanitization using the bootable media created earlier.
2. Select the desire option for media sanitization upon boot. Typically, the **default** mode is applicable for most cases.



3. Hit **Enter Key** to continue. The default sanitization mode is **short DoD 5520.22-M**, but this can be changed depending on the level your cybersecurity program indicates.
4. Follow the on-screen menu options to Start the Wiping process. Once the wipe has completed, you will see a screen like the image below.

[122] https://dban.org



5. Remove the physical hard drive from device post completion. It is now ready for disposal.

Additional Information

Not all hard drives can be wiped clean using this sanitization method. Media that is either SSD or flash memory is written differently than spinning drives, so follow SSD/Flash media vendors' recommendations for proper media sanitization for all non-spinning hard drives.

4.17.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the use of DBAN due to its typical installation and usage location (i.e., external to the manufacturing system).

4.17.7 Links to Entire Performance Measurement Data Set

N/A

4.18 Network Segmentation and Segregation

4.18.1 Technical Solution Overview

Network segmentation and segregation solutions enable a manufacturer to separate the manufacturing system network from other networks (e.g., corporate networks, guest networks), segment the internal manufacturing system network into smaller networks, and control the communication between specific hosts and services.

Each router's native capabilities were leveraged to implemented network segmentation.

4.18.2 Technical Capabilities Provided by Solution

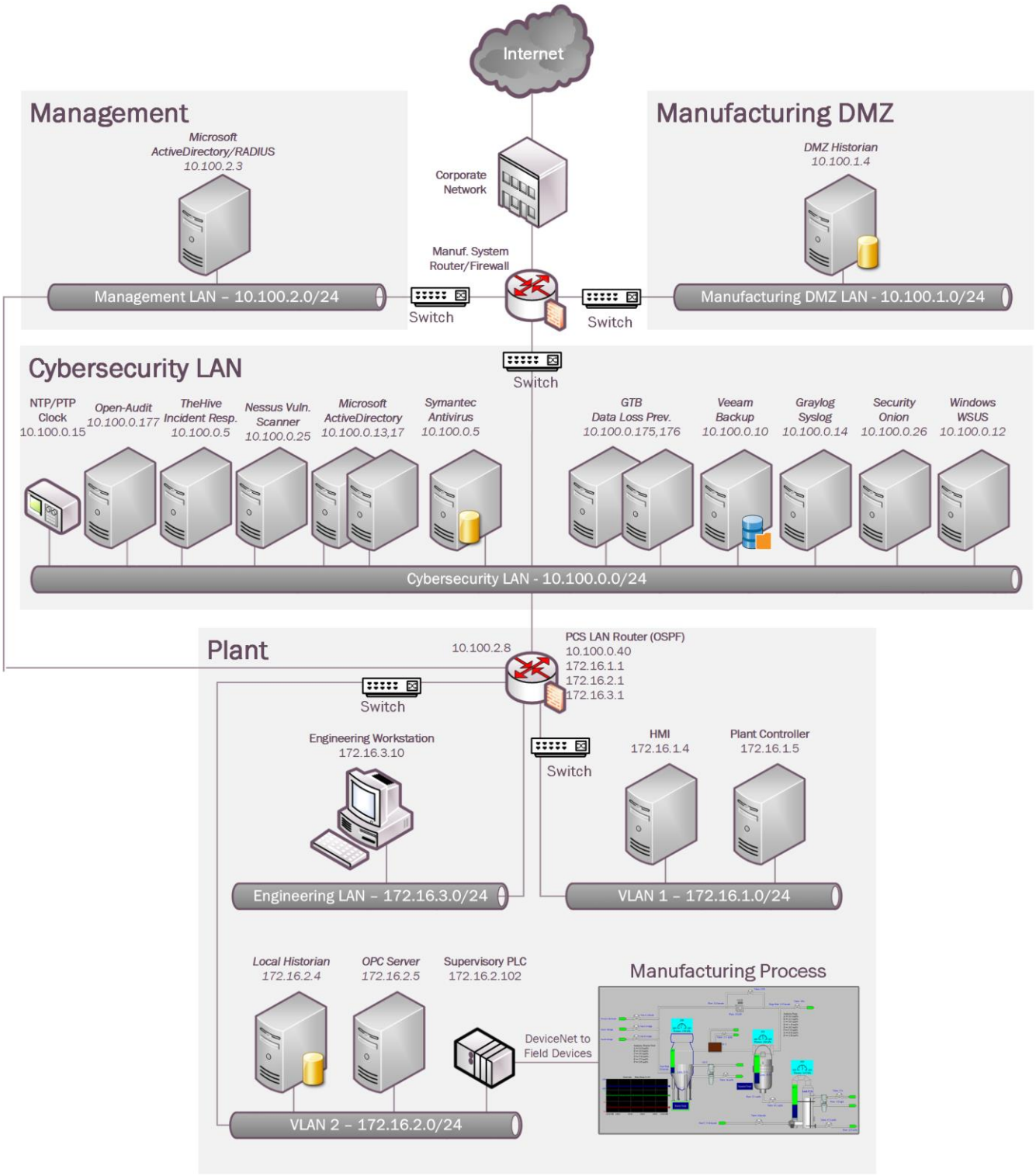
Network Segmentation and Segregation provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Network Segmentation and Segregation

4.18.3 Subcategories Addressed by Implementing Solution

PR.AC-5

4.18.4 Architecture Map of Where Solution was Implemented



4.18.5 Installation Instructions and Configurations

4.18.5.1 Environment Setup

The following devices were involved in implementing Network Segmentation:

Device	Details	Location
Cisco-ASA 5512	NGFW, running Firepower Services FTD 6.2.3	Manufacturing System
Allen Bradley Stratix 8300	Firewall, Router	Work cell

4.18.5.2 Segmentation in the Cybersecurity LAN

Following is a list of interfaces created on the Boundary Router/Firewall – Cisco ASA of the Cybersecurity LAN network:

Interface	IP address of Interface	Subnet	Description
GE 0/0	129.6.66.x	129.x.x.x/x	Uplink to Corporate
GE 0/1	10.100.0.1	10.100.0.0/24	Cybersecurity LAN
GE 0/2	129.6.1.x	129.x.x.x/x	VPN users
GE 0/3	10.100.2.1	10.100.2.0/24	Management LAN
GE 0/4	10.100.1.1	10.100.1.0/24	Manufacturing DMZ LAN

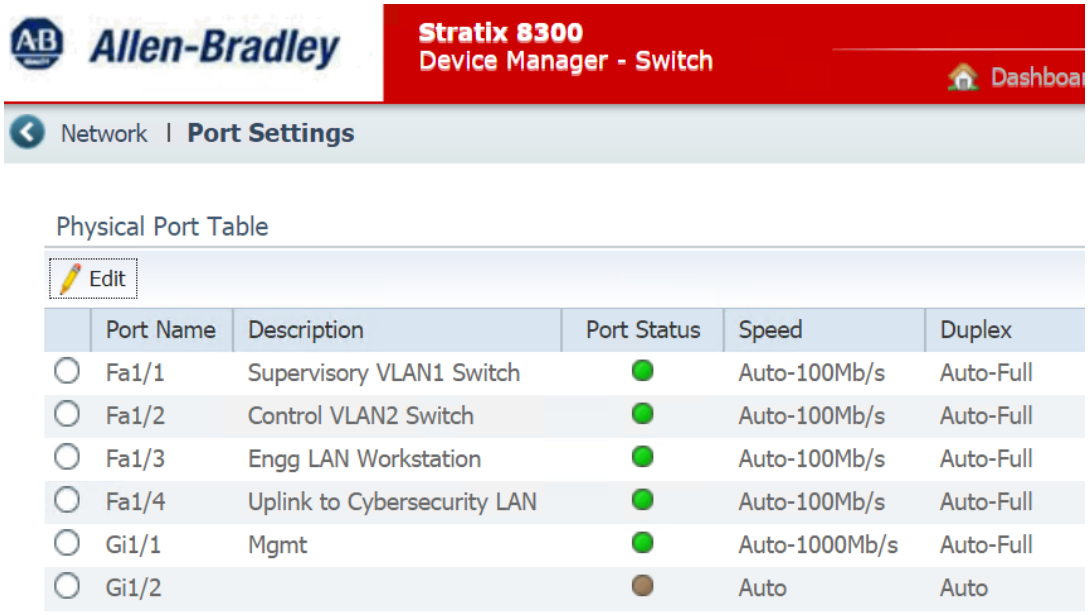
4.18.5.3 Segmentation in the Plant

The Work Cell consists of the following network devices:

Type	Description
Allen Bradley Stratix 8300	Boundary protection Firewall, Router
Allen Bradley Stratix 5700	Layer-2 Switch for the Control Network
Allen Bradley Stratix 5700	Layer-2 Switch for the Supervisory Network

List of interfaces created on the Boundary Router – Allen Bradley 8300:

Interface	IP address of Interface	Subnet	Description
Fa 1/1	172.16.1.1	172.16.1.0/24	Supervisory Vlan1
Fa 1/2	172.16.2.1	172.16.2.0/24	Control Vlan1
Fa 1/3	172.16.3.1	172.16.3.0/24	Engineering LAN
Fa 1/4	10.100.0.40		Uplink to Cybersecurity LAN
Gi 1/1	10.100.2.8		Management interface



One of the Stratix 5700 switches was connected to the Fa1/1 interface of the 8300 Router and used for the Supervisory (Vlan1) sub-network. Devices connected to this switch were assigned an IP address from the 172.16.1.0/24 subnet.

The other Stratix 5700 switch was connected to the Fa 1/2 interface of the Router and used for the Control (Vlan2) sub- network. Devices connected to this switch were assigned an IP address from the 172.16.2.0/24 subnet.

4.18.6 Highlighted Performance Impacts

No performance measurement experiments were performed for network segmentation and segregation due to it being implemented on the PCS before the Manufacturing Profile implementation was initiated.

4.18.7 Links to Entire Performance Measurement Data Set

N/A

4.19 Network Boundary Protection

4.19.1 Technical Solution Overview

Boundary Protection devices are implemented to monitor and control connections and communications at the external boundary and key internal boundaries within the organization. Boundary protection mechanisms include for example, routers, firewalls, gateways, data diodes separating system components into logically separate networks and sub networks.

4.19.2 Technical Capabilities Provided by Solution

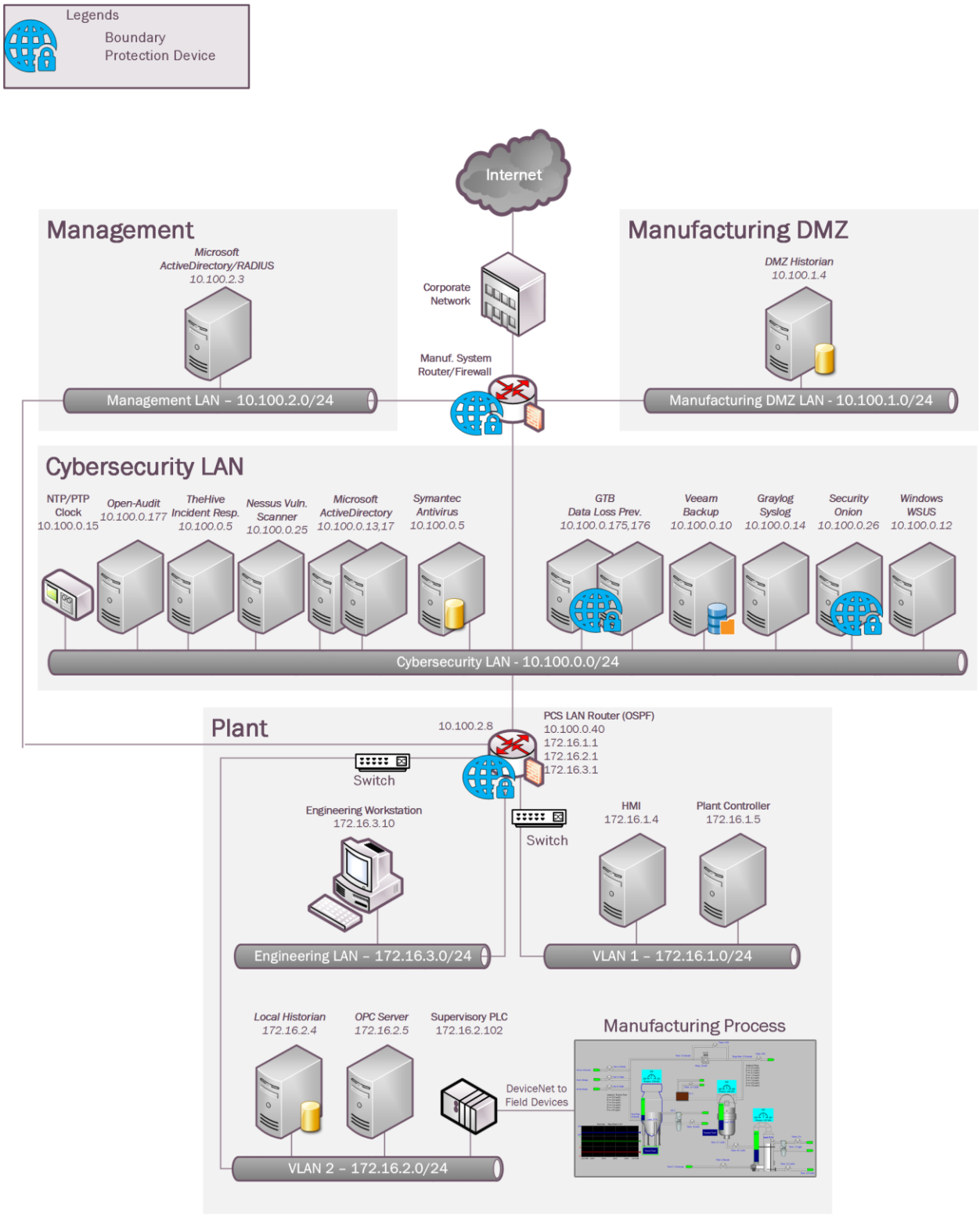
Network Boundary Protection provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Network Boundary Protection

4.19.3 Subcategories Addressed by Implementing Solution

PR.AC-5, PR.PT-4, DE.CM-1

4.19.4 Architecture Map of Where Solution was Implemented



4.19.5 Installation Instructions and Configurations

4.19.5.1 Environment Setup

The following devices were implemented for Boundary protection:

Device	Details	Location
Cisco-ASA 5512	NGFW, running Firepower Services FTD 6.2.3	Manufacturing System
Allen Bradley Stratix 8300	Firewall, Router	Work cell
GTB Inspector	Data Loss Prevention (DLP) virtual appliance	Cybersecurity LAN
Security Onion	Running Snort, BRO IDS	Cybersecurity LAN

4.19.5.2 Configuration on Cisco-ASA

The following features, settings were enabled on the ASA firewall:

- Network Segmentation
- ACL Rules
- NAT policy for Internet access
- Snort Inspection
- DMZ network

Network Segmentation

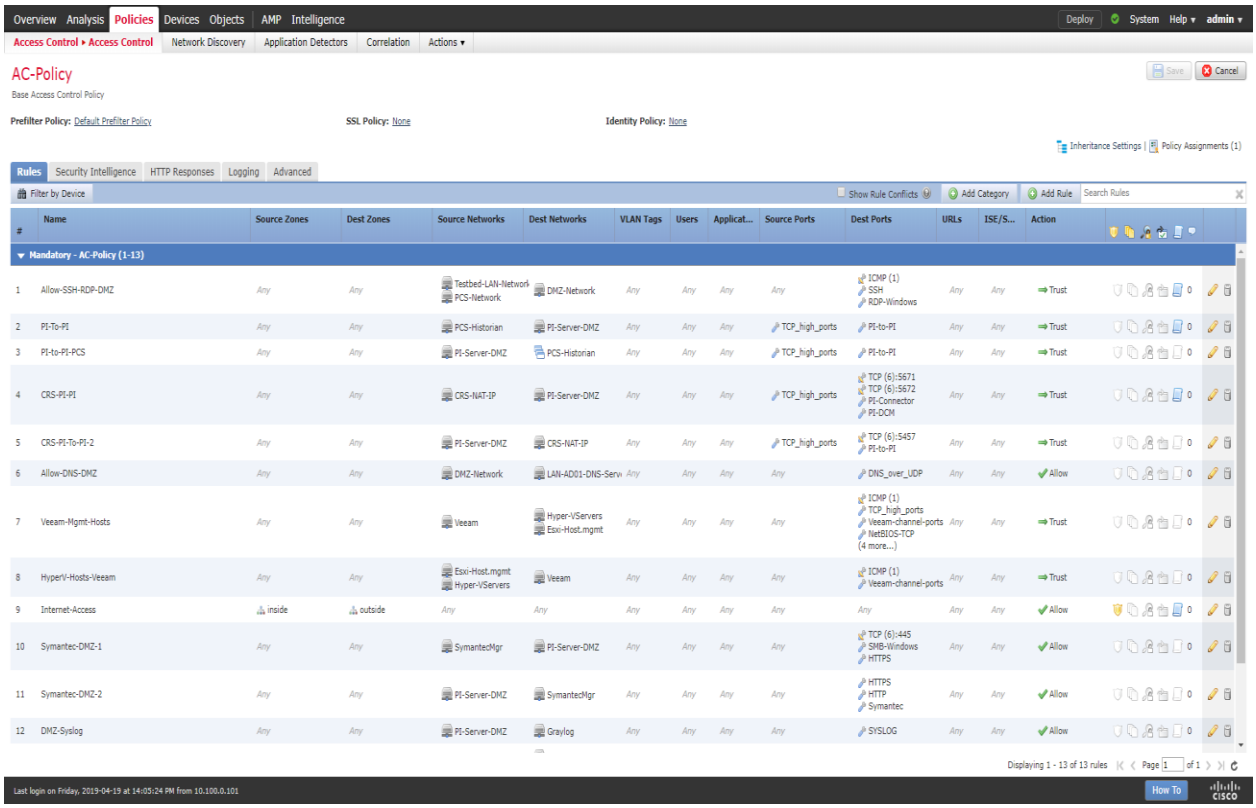
Separate network interfaces were configured for the different network segments as listed below:

- Inside Interface (Network: 10.100.0.0/24)
- DMZ Interface (Network: 10.100.1.0/24)
- Outside Interface (Network:129.6.91.x/24, Uplink to NIST Corporate for Internet)
- Public interface (Network:129.6.1.x/24 For VPN Users)

Access Control List (ACL) rules

The following rules were put in place on the ASA with a default Action to **Block all traffic**.

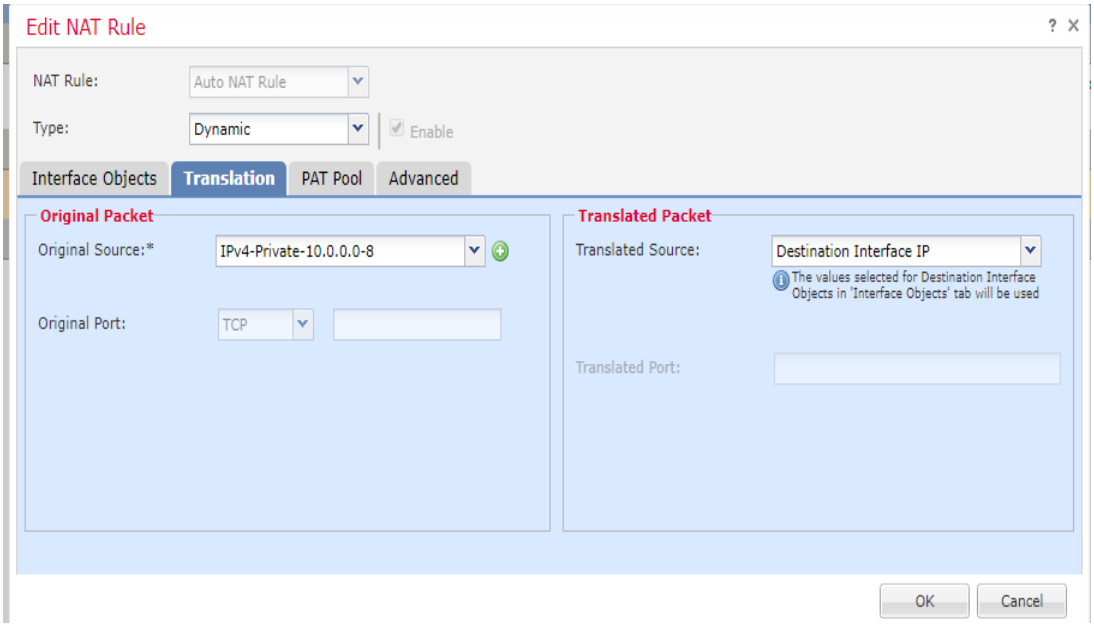
Source	Source Port	Destination	Dest Ports	Protocol	Action
10.100.0.0/24, 172.16.0.0/22	Any	DMZ network	SSH,RDP,ICMP	TCP	Trust
PCS-Historian (172.16.2.14)	TCP_High_Ports	DMZ-Historian	5450	TCP	Trust
DMZ Historian	TCP_High_Ports	PCS-Historian	5450	TCP	Trust
CRS-NAT (10.100.0.20)	TCP_High_Ports	DMZ-Historian	5450, 5460, 5671, 5672	TCP	Trust
DMZ Historian	TCP_High_Ports	CRS-NAT (10.100.0.20)	5457, 5450	TCP	Trust
DMZ Historian	Any	Active Directory (10.100.0.17)	53	UDP	Allow
Veeam Server	Any	Hyper-V Host servers, Esxi Host Server	NETBIOS, ICMP, HTTPS, 445, TCP_High_ports, 2500-5000, 6160-6163	TCP	Trust
Hyper-V Host Servers, Esxi Host Server	Any	Veeam Server	ICMP, 2500-5000	TCP	Trust
inside_interface	Any	outside_interface	Any	Any	Allow
DMZ Historian	Any	Symantec Server	SMB (445), HTTPS	TCP	Trust
Symantec Server	Any	DMZ Historian	HTTP, HTTPS, 8014	TCP	Trust
DMZ Historian	Any	Graylog Server	514	UDP	Trust
VPN_Pool (192.168.100.10 - .20)	Any	PCS-HMI-Server, PCS-Workstation	3389	TCP	Allow



NAT Policy

A Dynamic NAT policy was configured to allow internet access:

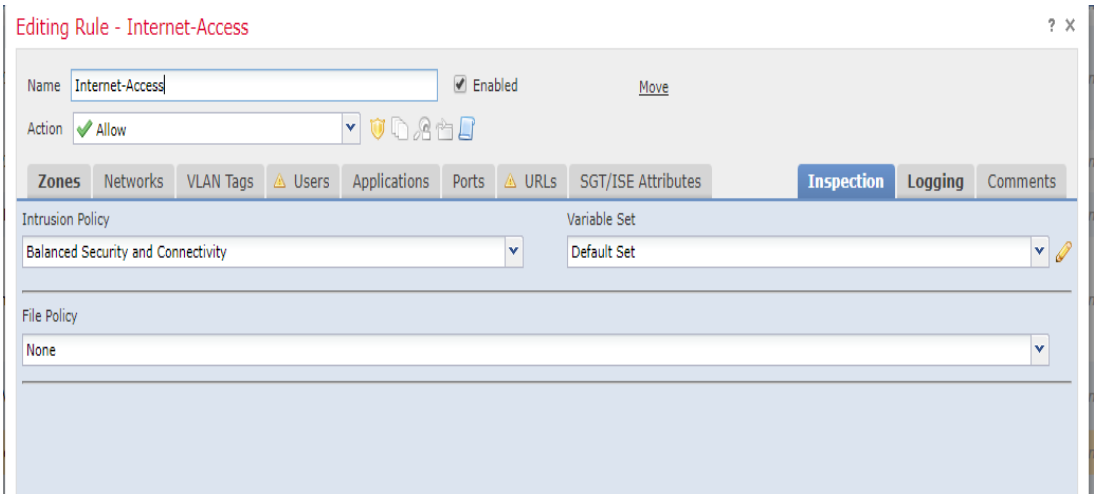
Type of NAT rule	Auto NAT
Source Interface	inside
Destination Interface	outside
Original sources	10.100.0.0/8
Translated Source	Destination Interface IP
Options	Translate DNS Replies that match this Rule: False



Snort Inspection

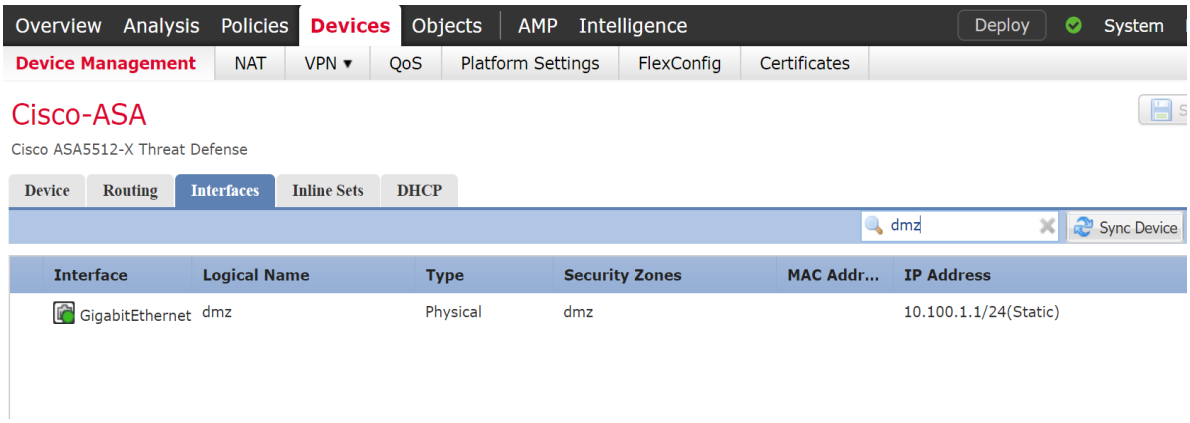
Snort Inspection was enabled on the following ACL rules:

Name of the ACL	Intrusion Policy
Allow-DNS-DMZ	Balanced connectivity and security
Internet-Access rule	Balanced connectivity and security
VPN-Rule	Balanced connectivity and security



DMZ Network

A Separate interface was setup for the Manufacturing DMZ LAN Network for hosting the **DMZ Historian** server.



4.19.5.3 Configuration of Allen Bradley Firewall:

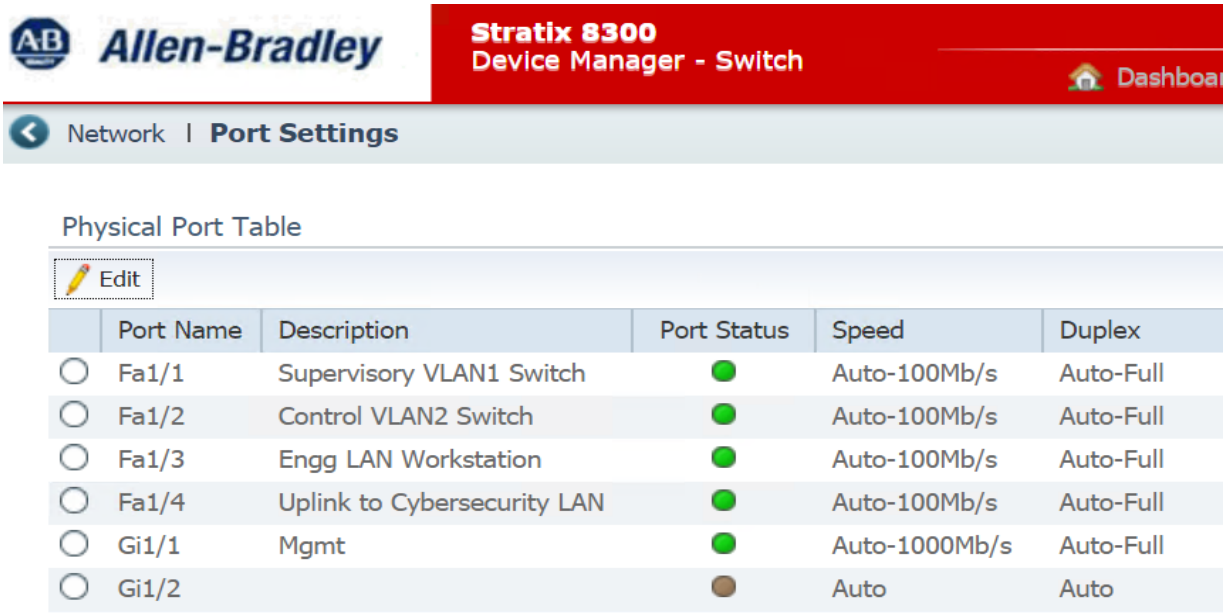
The following features and settings were enabled on this firewall:

- Network Segmentation
- ACL Rules

Network Segmentation

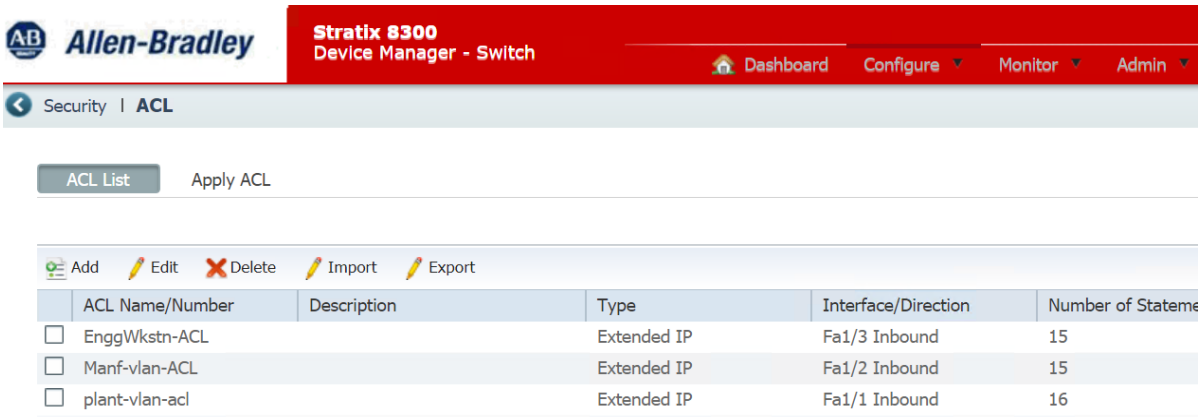
Separate network interfaces were configured for the different network segments as listed below:

- Supervisory VLAN1 (Network: 172.16.1.0/24)
- Control VLAN2 Interface (Network: 172.16.2.0.0/24)
- Engineering LAN (Network: 172.16.3.0/24)
- Uplink (IP:10.100.0.40, Uplink to Cybersecurity LAN)
- Management interface (IP:10.100.2.8)



Access Control List (ACL) rules

Three ACLs of Extended type were created as shown below. Each one was associated to a specific network interface as an Inbound ACL:



Port Name	Inbound ACL	Outbound ACL
Fa1/1	plant-vlan-acl	None
Fa1/2	Manf-vlan-ACL	None
Fa1/3	EnggWkstn-ACL	None
Fa1/4	None	None

Shown below is the snippet of these ACLs from the Firewall's running-config:

```
ip access-list extended EnggWkstn-ACL
  permit ip host 172.16.3.10 10.100.0.0 0.0.0.255
  permit tcp host 172.16.3.10 172.16.1.0 0.0.0.15 eq 3389
  permit tcp host 172.16.3.10 172.16.2.0 0.0.0.15 eq 3389
  permit icmp host 172.16.3.10 any
  permit tcp host 172.16.3.10 host 172.16.2.102 eq 44818
  permit ip host 172.16.3.10 host 172.16.3.1
  permit ip host 172.16.3.10 host 172.16.2.2
  permit ip host 172.16.3.10 host 172.16.1.3
  permit tcp host 172.16.3.10 host 10.100.1.4 eq 3389
  permit tcp host 172.16.3.10 host 129.6.1.2 eq ftp
  permit tcp host 172.16.3.10 host 129.6.1.2 eq 22
  permit tcp host 172.16.3.10 host 129.6.1.2 eq www
  permit tcp host 172.16.3.10 host 172.16.2.102
  permit tcp 192.168.100.0 0.0.0.255 host 172.16.3.10 eq 3389
  permit tcp host 172.16.3.10 host 192.168.100.10 gt 49000
```

```
ip access-list extended Manf-vlan-ACL
 permit ip 172.16.2.0 0.0.0.15 172.16.1.0 0.0.0.15 log
 permit icmp 172.16.2.0 0.0.0.255 any log
 permit tcp 172.16.2.0 0.0.0.255 host 172.16.3.10 gt 49000 log
 permit ip 172.16.2.0 0.0.0.255 host 10.100.0.5 log
 permit ip 172.16.2.0 0.0.0.255 host 10.100.0.10 log
 permit ip 172.16.2.0 0.0.0.255 host 10.100.0.13 log
 permit ip 172.16.2.0 0.0.0.255 host 10.100.0.17 log
 permit ip 172.16.2.0 0.0.0.255 host 10.100.0.25 log
 permit ip 172.16.2.0 0.0.0.255 host 10.100.0.177 log
 permit tcp 172.16.2.0 0.0.0.255 host 10.100.0.234 log
 permit tcp 172.16.2.0 0.0.0.255 host 10.100.0.12 eq www log
 permit tcp 172.16.2.0 0.0.0.255 host 10.100.0.12 eq 443 log
 permit tcp 172.16.2.0 0.0.0.255 host 10.100.0.12 eq 8530 log
 permit udp 172.16.2.0 0.0.0.255 host 10.100.0.14 eq syslog

ip access-list extended plant-vlan-acl
 permit ip 172.16.1.0 0.0.0.15 172.16.2.0 0.0.0.15 log
 permit icmp 172.16.1.0 0.0.0.255 any log
 permit tcp 172.16.1.0 0.0.0.255 host 172.16.3.10 gt 49000 log
 permit ip 172.16.1.0 0.0.0.255 host 10.100.0.5 log
 permit ip 172.16.1.0 0.0.0.255 host 10.100.0.10 log
 permit ip 172.16.1.0 0.0.0.255 host 10.100.0.13 log
 permit ip 172.16.1.0 0.0.0.255 host 10.100.0.17 log
 permit ip 172.16.1.0 0.0.0.255 host 10.100.0.25 log
 permit tcp 172.16.1.0 0.0.0.255 host 10.100.0.234 log
 permit udp 172.16.1.0 0.0.0.255 host 10.100.0.14 eq syslog log
 permit tcp 172.16.1.0 0.0.0.255 host 10.100.0.12 eq www log
 permit tcp 172.16.1.0 0.0.0.255 host 10.100.0.12 eq 443 log
 permit tcp 172.16.1.0 0.0.0.255 host 10.100.0.12 eq 8530 log
 permit ip 172.16.1.0 0.0.0.255 host 10.100.0.177 log
 permit tcp 192.168.100.0 0.0.0.255 host 172.16.1.4 eq 3389 log
 permit tcp host 172.16.1.4 192.168.100.0 0.0.0.255 gt 49000
log
```

4.19.5.4 Configuration of GTB Inspector:

Refer to Section 4.15 for details.

4.19.5.5 Configuration of Security Onion:

Refer to Section 4.7 for details

4.19.6 Highlighted Performance Impacts

The following performance measurement experiment was performed for the network boundary protection while the manufacturing system was operational:

Experiment PL004.1- Firewall rules are activated at the PCS boundary router

There was no significant performance impact observed when firewall rules were activated. For example, the packet round trip time between the HMI and OPC remained mostly constant before and after the firewall rules were activated.

Care needs to be used for implementation of the rules and a thorough understanding of the system is important. A misconfigured firewall rule can block a legitimate connection and cause system failure.

In the PCS system implementation, a thorough analysis on network connections was performed to identify all the legitimate connections in order to implement the firewall rules. Some network connections are legitimate but not obvious or only stayed connected for a short amount of time. Validation test was performed to ensure all the legitimate network connections for normal operation are allowed. The implementation and validation tests were completed during a planned system down time.

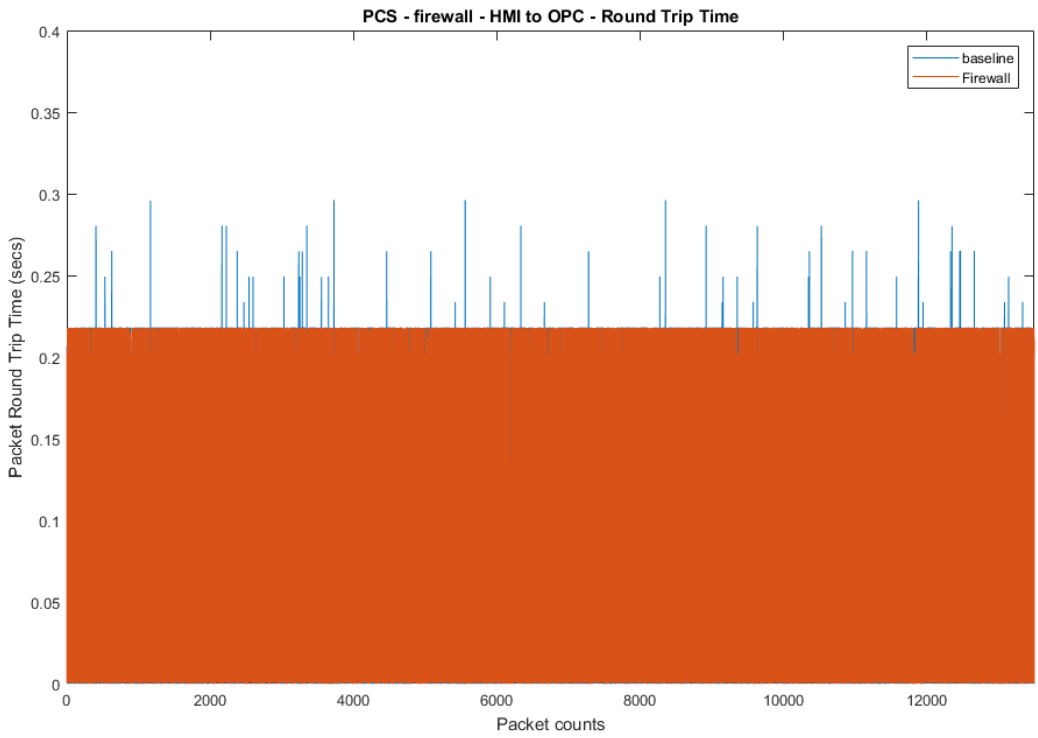


Figure 4-35 Packet round trip time from HMI to OPC before and after firewall rules were activated

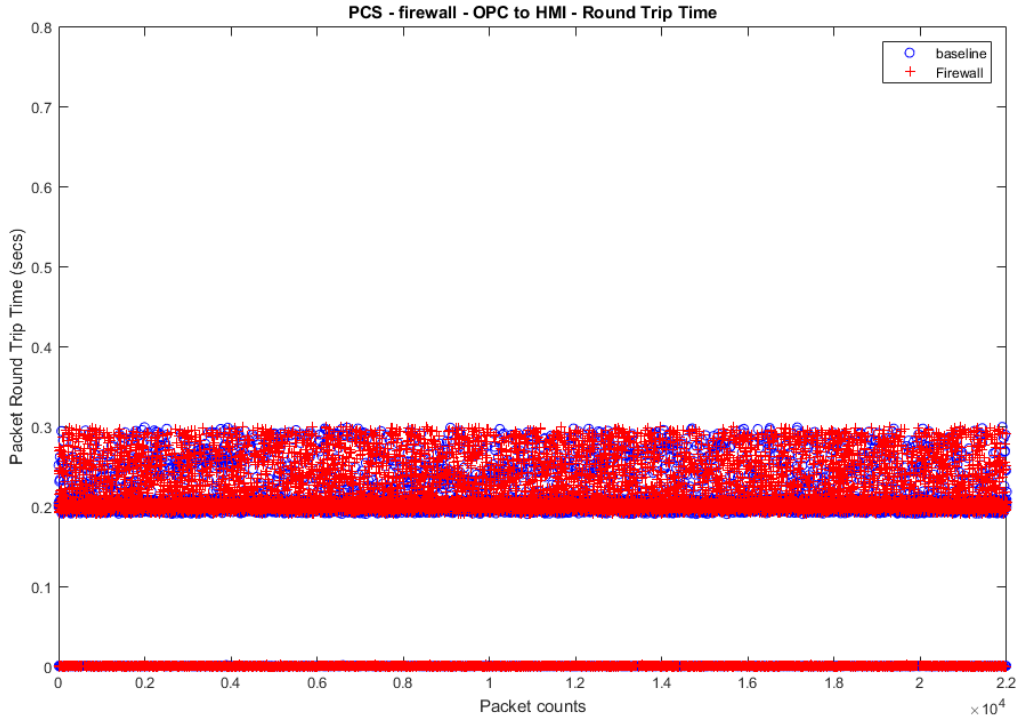


Figure 4-36 Packet round trip time from OPC to HMI before and after firewall rules were activated

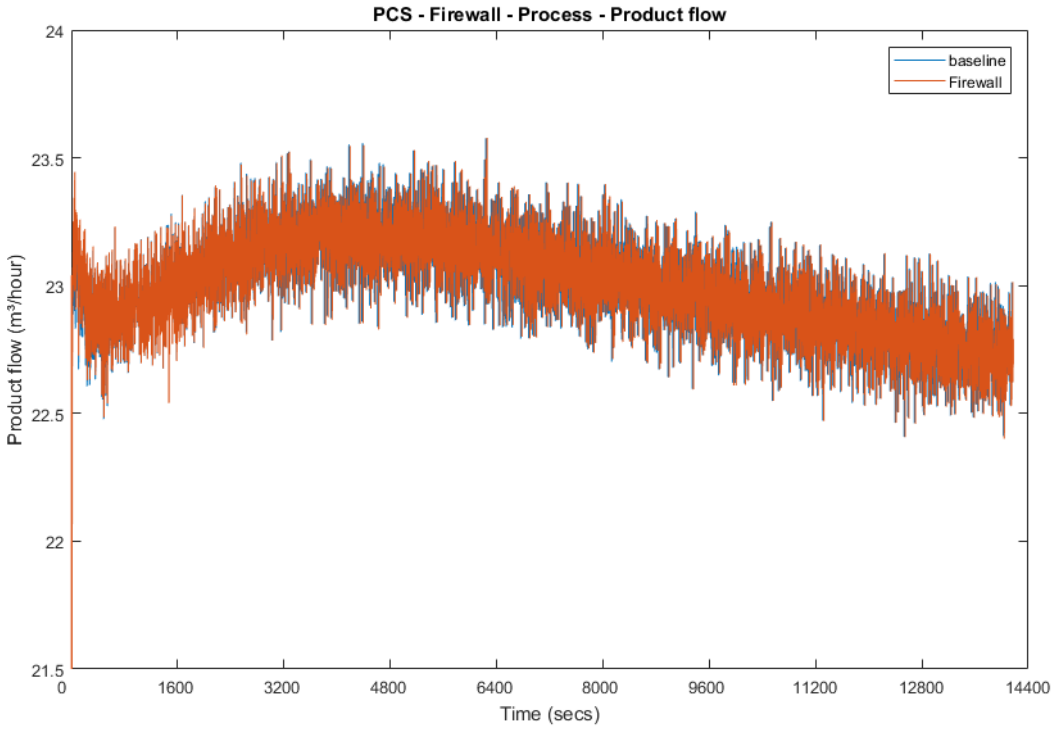


Figure 4-37 Manufacturing process product flow rate before and after firewall rules were activated

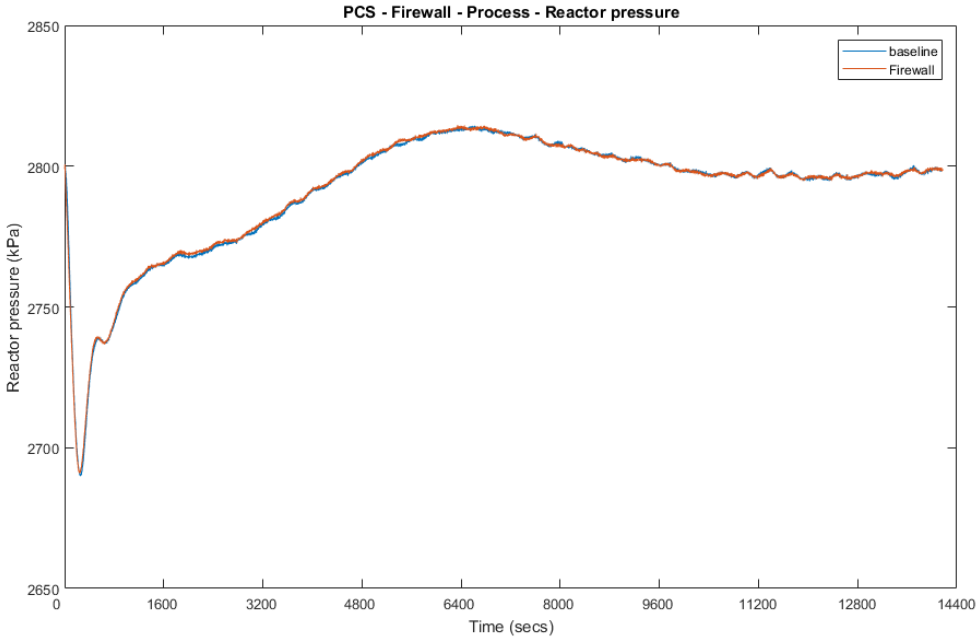


Figure 4-38 Manufacturing process reactor pressure before and after firewall rules were activated

4.19.7 Links to Entire Performance Measurement Data Set

- **Firewall KPI data**
- **Firewall measurement data**

4.20 Managed Network Interfaces

4.20.1 Technical Solution Overview

Managing network interfaces controls what network devices are plugged into switches within the manufacturing system, along with physical labeling of the connections to help with system identification and classification. Required actions will be performed directly on the exterior of the switch. Switch port in use will be labeled logically within switch console itself, along with the corresponding network cable for easy identification. All cable should be labeled/identified at the switch and at the opposite end of the network cable. Switch Port Security should be configured to restrict access to only allowed preconfigured Media Access Control (MAC) addresses devices.

There is a minimal cost for labeling. The effort to implement can be high, but not difficult. The effort will be spent taking the required time to accurately identify cabling connections.

Most switches have built in Port security. Since this technical control is built into switches there is no additional cost for implementation. Configuration for Port security is well documented and easily configured.

4.20.2 Technical Capabilities Provided by Solution

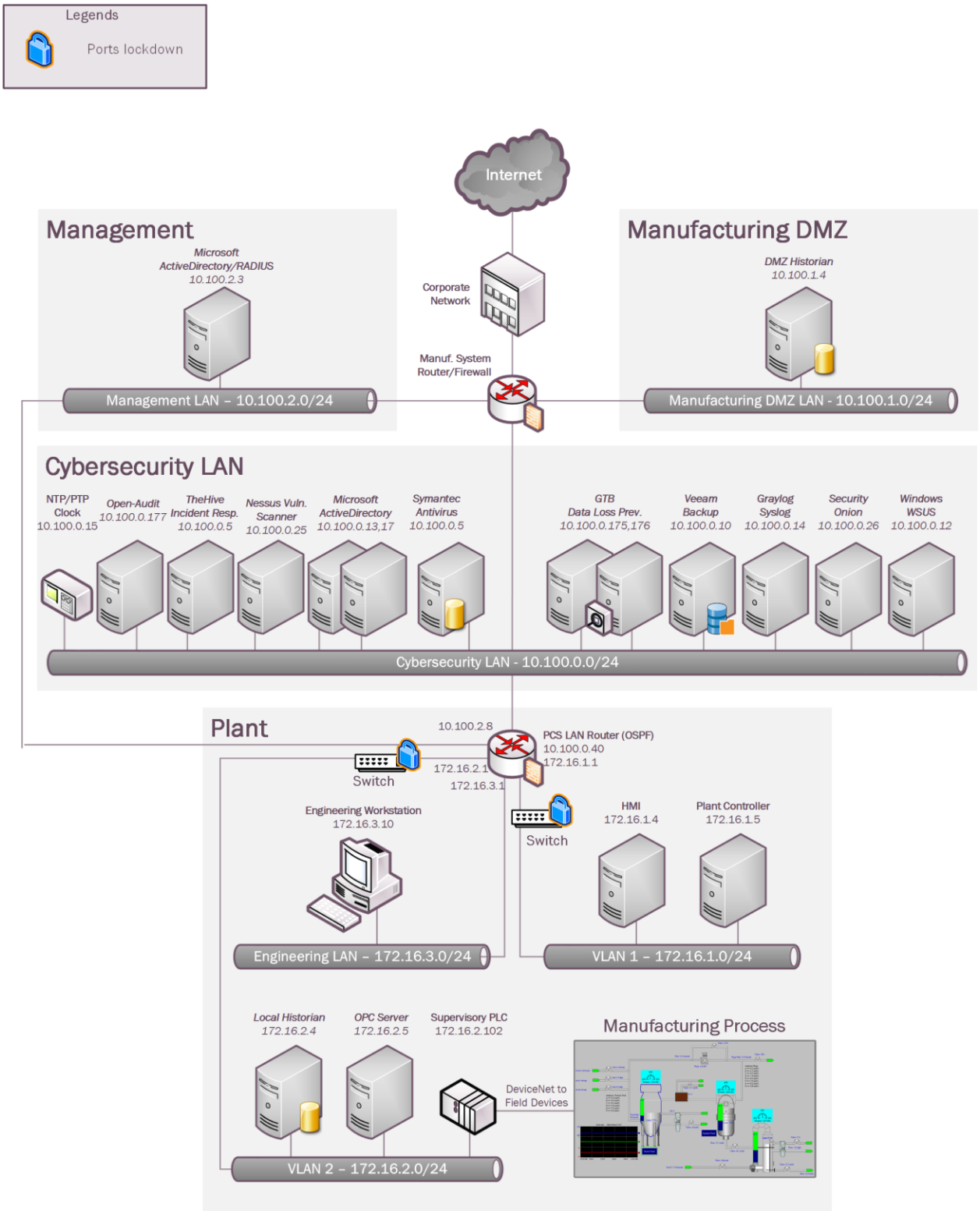
Managed Network Interfaces provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Managed Network Interfaces

4.20.3 Subcategories Addressed by Implementing Solution

PR.AC-5

4.20.4 Architecture Map of Where Solution was Implemented



4.20.5 Installation Instructions and Configurations

The following actions were performed for implementing Managed Network Interfaces.

4.20.5.1 Port Labelling:

Port labeling provides ability for others to understand and know what network devices belong where. Managing your switches with correct labeling and classification makes troubleshooting simpler along with improving cybersecurity.

1. Configure Port labelling on the Allen Bradley Router and switches as follows:
    a. Login to the Switch / Router via web browser
    b. Click on **Configure > Port Settings**.
    c. Click **Edit on the** Port **to be labelled**.
    d. Type into **Description field** the desired label.
    e. Click **OK** to save changes and exit.
2. Alternatively, the cli commands for labelling the ports are:

```
#enable
#configure terminal
(config)#Interface FastEthernet1/3
description <label>
(config)#end
#wr mem
```

4.20.5.2 Port Security Configuration

Port security or MAC address filtering is a security method for access control. Using this method, we can blacklist, or whitelist certain devices based on their MAC address. This prevents unauthorized devices from being plugged into a network switch while trying to obtain sensitive information, which could be used for mapping out network connections for possible data exfiltration. When an unauthorized device is plugged into a protected port a warning message is logged and sent to a syslog server if supported by switch vendor.

1. Configure Port Security on the Allen Bradley Router and switches as follows:
    a. Login to the device via web browser.
    b. Click, **Configure > Security > Port Security**
    c. Click **Edit** button upon selecting the desired port requiring security.
    d. Check in a box next to **Enable.** Click **Add Learned MAC Addresses** or Add the Addresses manually.
    e. Click **OK** to save changes once MAC addresses have been added.
    f. Change **Maximum MAC Count** to the required MACs being assigned to this port, if more than one MAC addresses are required to be added.

Snippet of the Allen Bradley Boundary Router running config in the plant:

```
Interface FastEthernet1/3
description Engg LAN Workstation
switchport mode access
switchport port-security mac-address  40a8.f03d.48aw
switchport port-security
ip access-group EnggWkstn-ACL in
```

Snippet of the Allen Bradley Switch running config in the plant network:

```
Interface FastEthernet1/1
Switchport access vlan 102
switchport mode access
switchport port-security mac-address e490.693b.c2c7
switchport port-security
```

4.20.5.3 Disabling Unused ports

1. Disable unused ports on the Allen Bradley Router and switches as follows:
    a. Click **Configure > Port Settings** while on the homepage.
    b. Find all Operational Mode labeled as **down** to identify ports being disabled.
    c. Select the **down** ports and click **Edit.**
    d. Remove check for **Enable from Administrative** in the **Edit Physical Port** window. Click **OK**. With the port now disabled, any device plugged into this port or other disabled ports will not work.

Snippet from the Allen Bradley Switch running config showing disabled ports:

```
Interface FastEthernet1/2
shutdown

Interface FastEthernet1/8
shutdown
```

4.20.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the managed network interfaces due to their implementation method (i.e., manually disable unused network interfaces in configuration).

4.20.7 Links to Entire Performance Measurement Data Set

N/A

4.21 Time Synchronization

4.21.1 Technical Solution Overview

Time synchronization allows devices to synchronize with a reliable time source. Time synchronization is vital for system logins, event tracking and all other time sensitive events occurring with a manufacturing system.

4.21.2 Technical Capabilities Provided by Solution

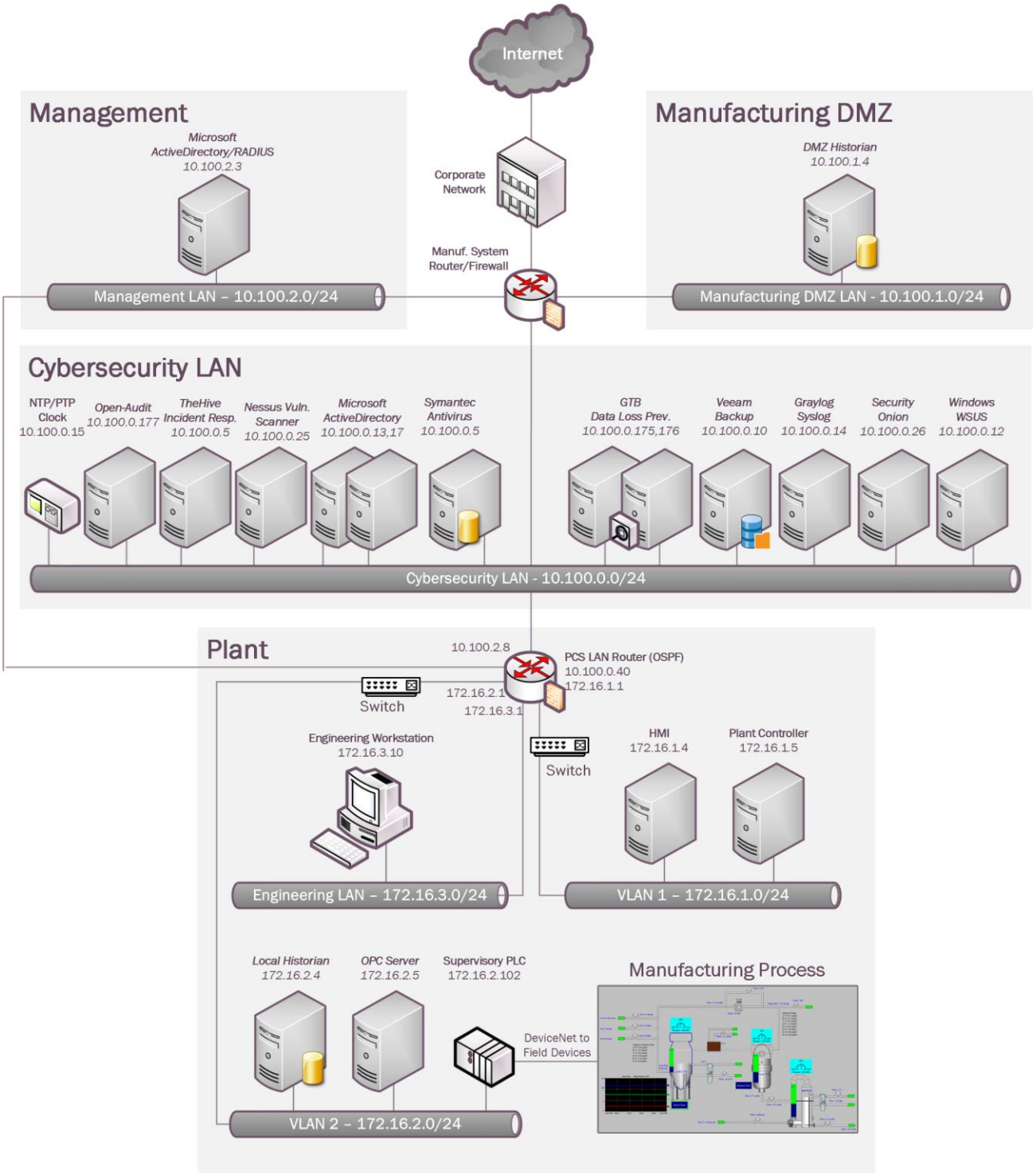
Time Synchronization provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Time Synchronization

4.21.3 Subcategories Addressed by Implementing Solution

PR.PT-1

4.21.4 Architecture Map of Where Solution was Implemented



4.21.5 Installation Instructions and Configurations

Details of the NTP server implemented:

Name	IP address	Purpose	Hardware Details
Grandmaster	10.100.0.15	NTP/PTP Clock	Model: Meinberg Lantime M900

4.21.5.1 Meinberg M900 Time Server

Industrial / Manufacturing environments typically need higher time accuracy than the ones provided by default capabilities of a typical Windows Active Directory environment. To accommodate this, an external hardware clock such as this one was implemented for higher time accuracy up to milliseconds level. This device was configured to obtain its Upstream time from the NIST Time server.

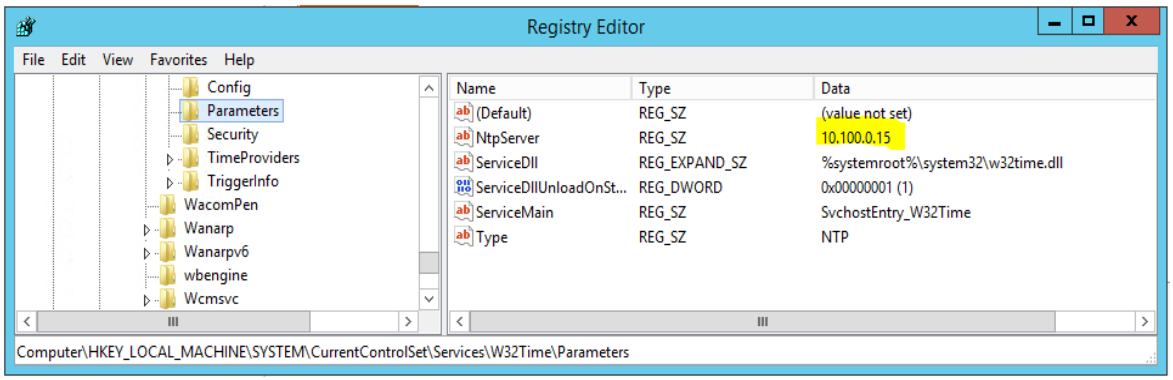
4.21.5.2 NTP Configuration on the Domain Controller

The Active Directory Domain controller holding the PDC Emulator role [123] in the manufacturing system was configured to obtain its time from the Meinberg Lantime M900 device.

Change the following registry key on the Domain Controller to have w32Time.exe sync its time from an external source IP address.

`HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\W32Time\Parameters\NtpServer`

The image below shows our Domain Controller pointing to the IP address of Meinberg LAN Time clock



[123] https://support.microsoft.com/en-us/help/197132/active-directory-fsmo-roles-in-windows

4.21.5.3 NTP Configuration on the Member-servers

All windows computers were joined to our Active Directory domain. Domain joined machines automatically sync their time by contacting local domain controller which is the Active Directory server.

4.21.5.4 NTP Configuration on Networking devices

All other devices such as Switches, Routers within the manufacturing system were configured to sync their time from the Meinberg M900 using NTP.

The NTP Settings on the Allen Bradley Boundary Router and Switches can be set as follows:

1. Login to the web interface of the router/switch.
2. Click on **Configure** > **NTP**
3. Click **Add** to add new time server.
4. Enter the *IP address* of the time source.
5. Click **Save**
6. **Logout** when done.

Additional Information

The master time reference selected should be as close to your physical location as possible. This should reduce the Off Set.

4.21.6 Highlighted Performance Impacts

No performance measurement experiments were performed for time synchronization due to its installation in the system before the Manufacturing Profile implementation was initiated.

4.21.7 Links to Entire Performance Measurement Data Set

N/A

4.22 System Use Monitoring

4.22.1 Technical Solution Overview

System use monitoring is accomplished by multiple tools to protect manufacturing system environment from harmful activities using data loss protection, system hardening and syslog server for monitoring, store and auditing. Each tool provides a different level required to protect the manufacturing system.

Implementation effort is moderate requiring understanding of Linux and Windows systems, along with virtual machine experience.

4.22.2 Technical Capabilities Provided by Solution

System Use Monitoring provides components of the following Technical Capabilities described in Section 6 of Volume 1:

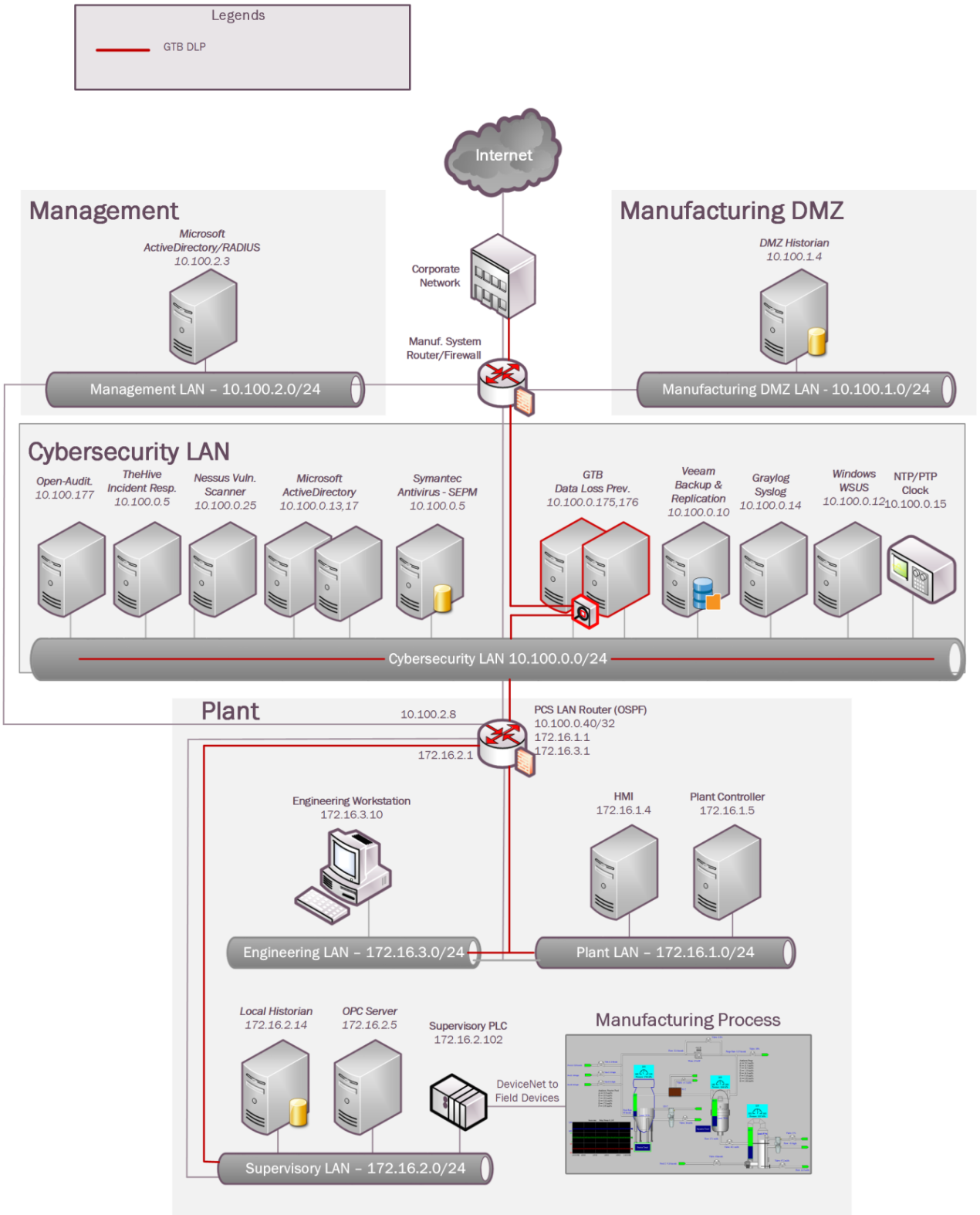
- System Use Monitoring

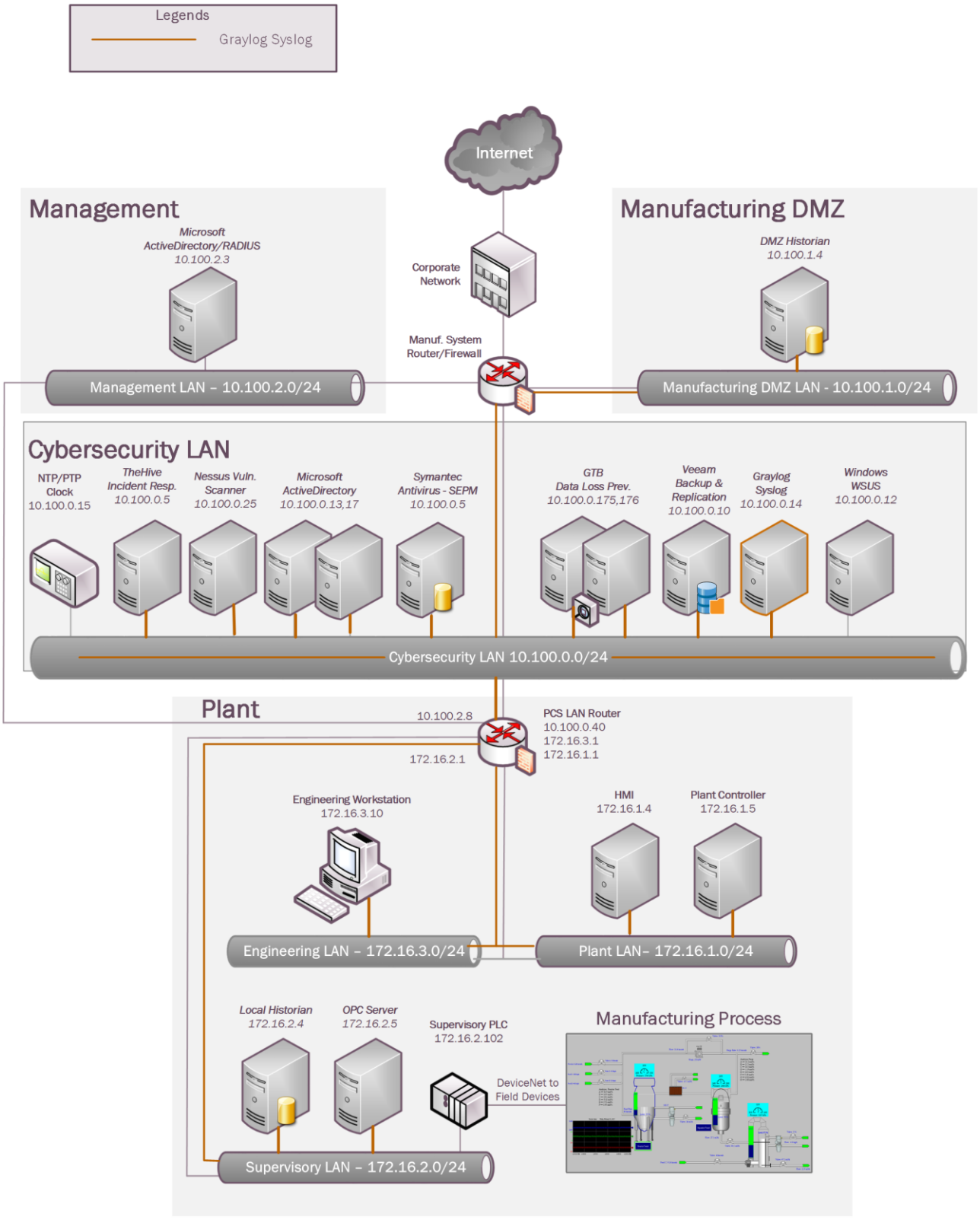
System Use Monitoring was provided by GTB Inspector, Ports and Services Lockdown, and Graylog.

4.22.3 Subcategories Addressed by Implementing Solution

PR.AC-1, PR.DS-5, PR.MA-2, DE.CM-3

4.22.4 Architecture Map of Where Solution was Implemented





4.22.5 Installation Instructions and Configurations

System use monitoring was implemented using a combination of tools such as GTB Inspector, Graylog and native Windows Server capabilities such as enabling auditing and restricting administrative user accounts.

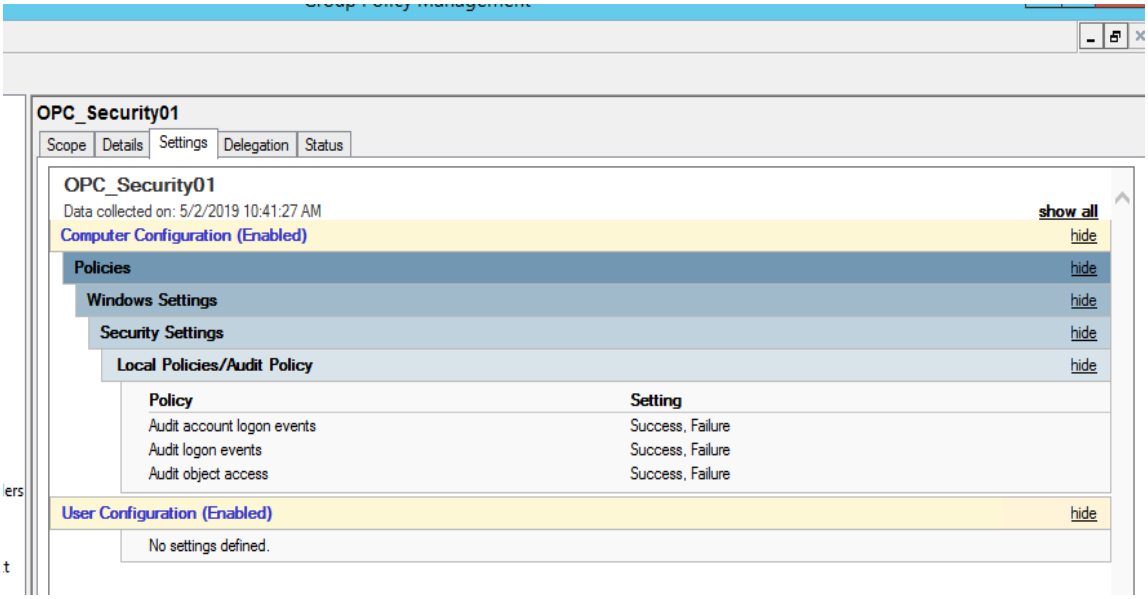
GTB DLP: See Section 4.15.5 for instructions.

Graylog: See Section 4.16.5 for instructions

4.22.5.1 Enabling Auditing on Windows

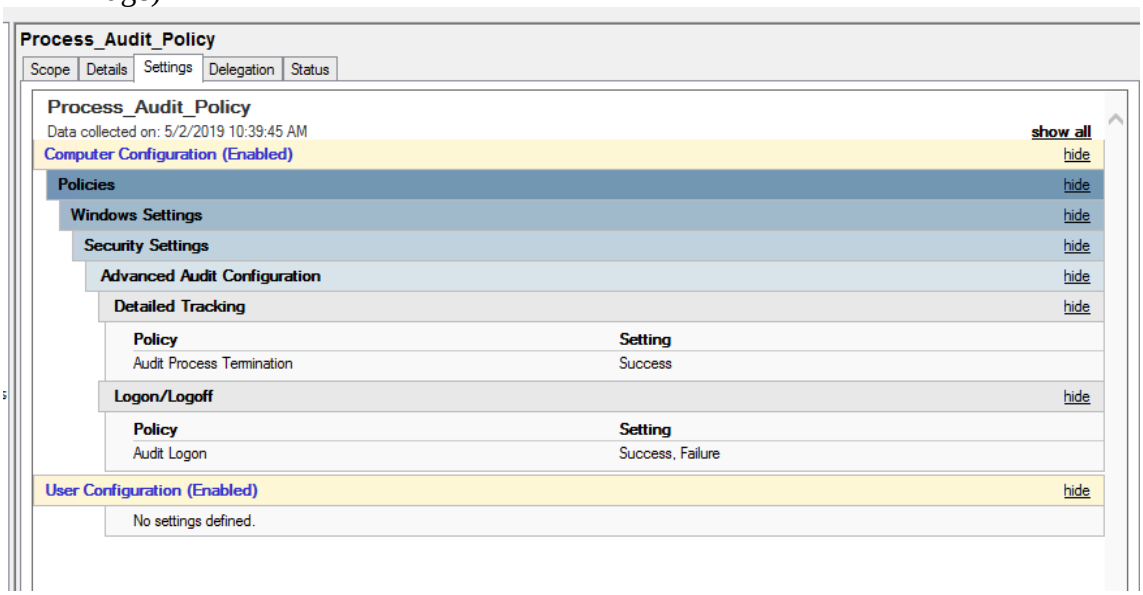
Auditing Logon events

a. Launch the Group Policy manager on the Domain controller by running `gpedit.msc`.
b. Edit either the **Default Domain Controller Group Policy** or create a new group policy object and link it to appropriate servers OU**.**
c. Navigate to **Computer Configuration** > **Polices**> **Windows Settings** >**Security Settings > Local Polices > Audit Policy**
d. Change the **Audit Account logon events, Audit logon events, Audit Object access** settings to reflect **Success**, **Failure.** See image below for reference**.**



Auditing Process Termination

a. Navigate to **Computer Configuration > Polices > Windows Settings > Security Settings > Advanced Audit Configuration**
b. Change **Detailed Tracking** and **Logon/Logoff** to **Success / Success, Failure** (See Image)



4.22.5.2 Windows - Restricting Administrative Users:

Review the local Administrators group on each system and add only those accounts that needed to have Administrative privileges on the system.

For instance: An AD service account **opc-admin** was created to run OPC-server services and was granted Administrative privileges on the 2 servers below:

- OPC Server
- Controller Server

4.22.5.3 Restricting Access to the PLC

Remote Access to PLC was regulated through the Firewall to allow access only from the Engineering workstation.

4.22.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the installation of GTB into the PCS due to its location within the network topology. No manufacturing process components across the boundary on a regular basis while the system is operational.

No performance measurement experiments were performed for the use of the Graylog due to its typical installation and usage location (i.e., external to the manufacturing system).

4.22.7 Links to Entire Performance Measurement Data Set

N/A

4.23 Ports and Services Lockdown

4.23.1 Technical Solution Overview

Ports and services lockdown solutions enable a manufacturer to discover and disable nonessential logical network ports and services. A logical port is a number assigned to a "logical" connection. Port numbers are assigned to a service, which is helpful to TCP/IP in identifying what ports it must send traffic to. Hackers use port scanners and vulnerability scanners to identify open ports on servers. By revealing which ports are open, the hacker can identify what kind of services are running and the type of system. Closing unnecessary ports by uninstalling unnecessary programs considerably reduces the attack surface. These actions need to be performed manually.

Native OS capabilities, Open-Audit and Nessus scanner were leveraged to inventory list of ports and applications currently running on each device of the plant.

4.23.2 Technical Capabilities Provided by Solution

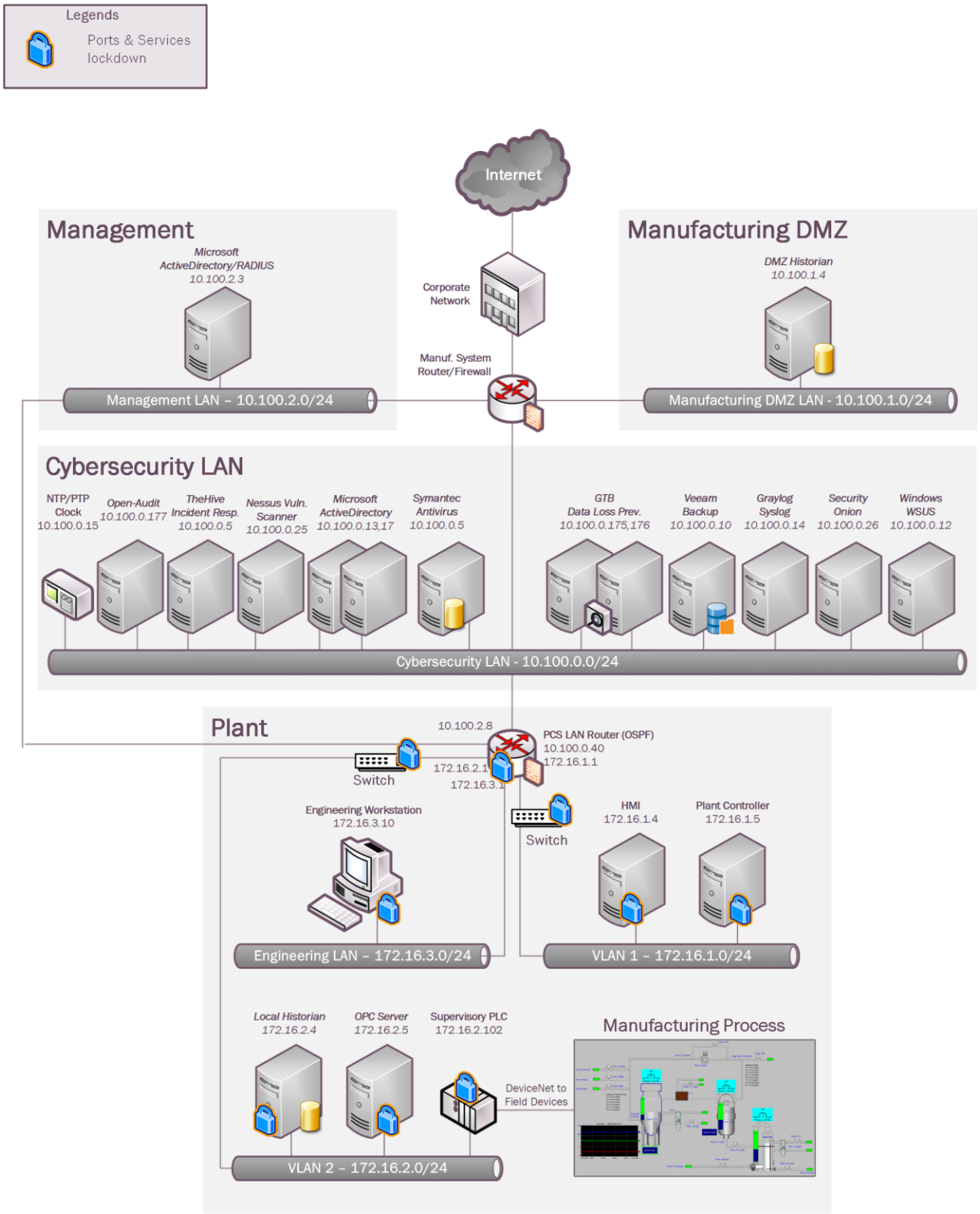
Ports and Services Lockdown provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Ports and Services Lockdown

4.23.3 Subcategories Addressed by Implementing Solution

PR.IP-1, PR.PT-3

4.23.4 Architecture Map of Where Solution was Implemented



4.23.5 Installation Instructions and Configurations

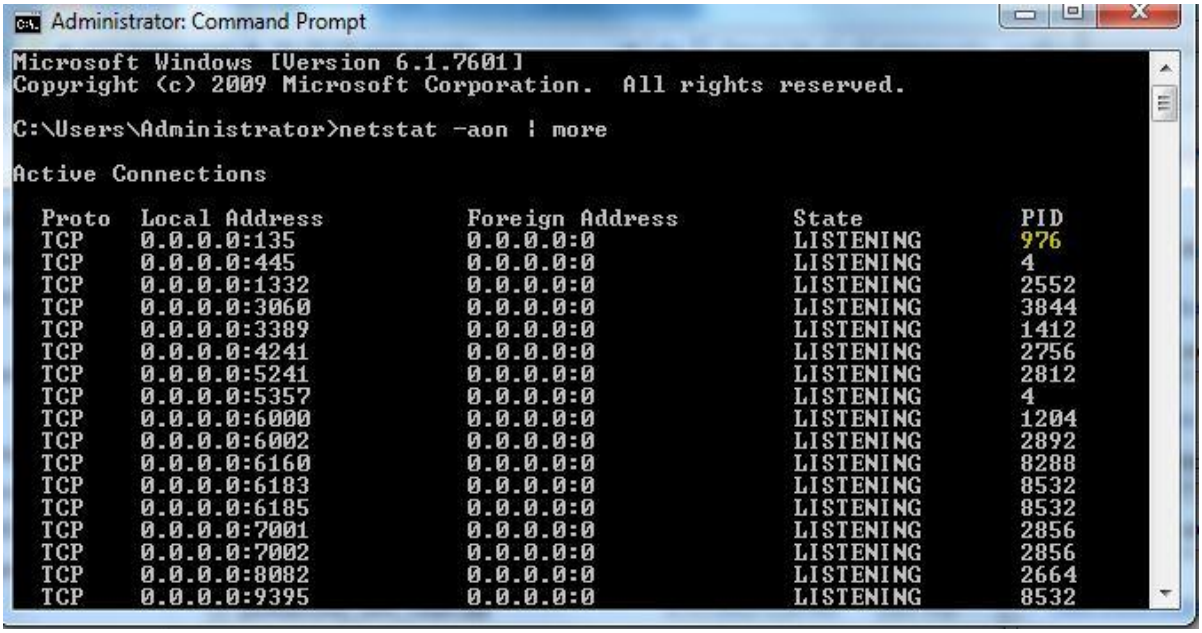
The following steps were performed on the Plant Infrastructure as part of Ports and Services Lockdown.

4.23.5.1 Removal of Unwanted programs from Windows systems:

The following guidelines can be used to identify unwanted programs for removal:

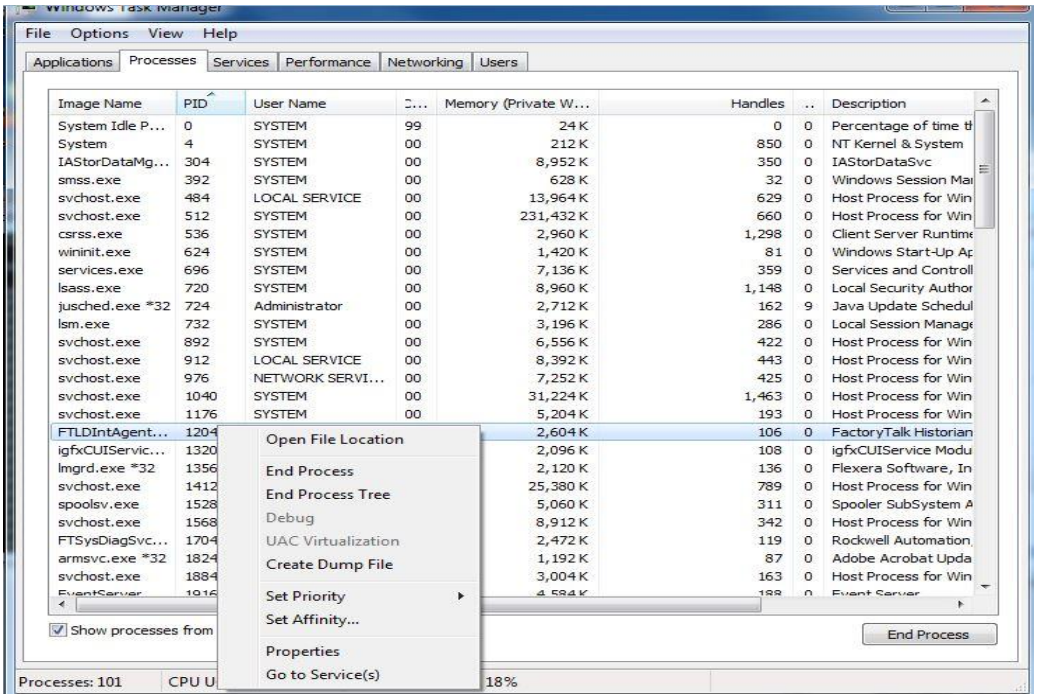
1. Perform a software inventory of each system using Open-Audit. Review the reports to identify a list of unwanted programs and uninstall them. This includes some software that comes by default with the OS.
2. Use Netstat utility to gather information about which applications are running or using which TCP/IP ports on each system

   For instance: `netstat -aon | more` will generate a list of processes and the associated process identifier (PID)

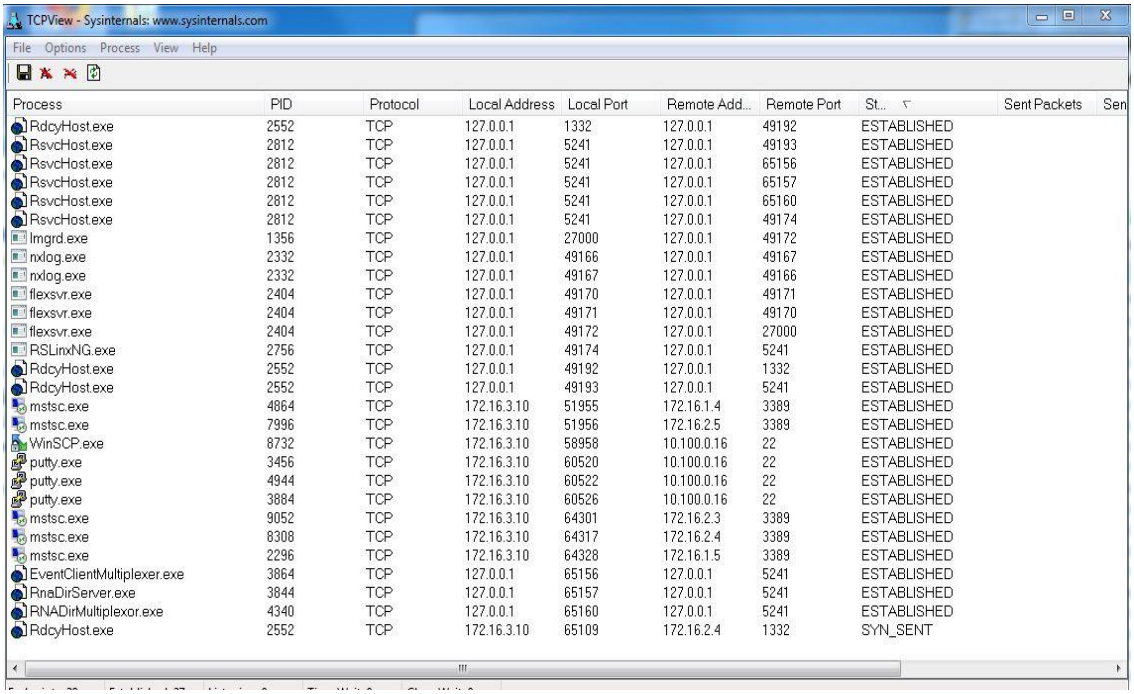


3. Use the PID from the above output with the Windows Task Manager for further analysis. Within Task Manager (Windows 7), enable the PID column by clicking on **View** > **Select Columns**.

4. Use **Show Processes for All Users** to search for the PID in the list. To end that process, Right Click > **Open File Location** or **Go to Service(s**) options to control the process or stop it.



5. Other alternatives are using **Resource Monitor** (resmon.exe) and **TCPView** from SysInternals. See the image below of TCPView for reference.



4.23.5.2 Disabling of Unsecure services on Network Devices

Use the following guidelines to disable unsecure services on all Allen Bradley devices of the Plant:

1. Disable unsecure services such as Telnet, SNMP (v1 and v2). If SNMP is required, change the default community string or use SNMP v3.
2. Set a password for enable mode using the following commands for reference

```
#enable
#configure terminal
(config)#enable secret <password>
```

4.23.5.3 Restrict ssh access

Run the following Cisco commands to restrict ssh access from select few networks.

```
 #enable
 #configure terminal
(config)#access-list 1 permit 172.16.0.0 0.0.255.255
(config)#line vty 0 15
(config)#access-class 1 in
```

4.23.5.4 Hardening the PLC

Follow these actions to harden the PLC.

1. Disable unsecure services such as Telnet, SNMP and HTTP.
2. Use Firewall rules to restrict Remote Access to the PLC from only the Engineering Workstation.

4.23.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the managed network interfaces due to their implementation method (i.e., manually disabled network ports and removed unwanted Windows programs and services).

4.23.7 Links to Entire Performance Measurement Data Set

N/A

4.24 Media Protection

4.24.1 Technical Solution Overview

Hardware-based port locks provide a low-cost solution for protecting USB ports. Implementation and ease of use provide for quick install and easy removal. USB Port locks provide a simple yet effective solution to restrict USB use. Once USB Port lock has been inserted and engaged there is no way of removing the lock device without damaging the USB port unless a key is used. Each USB Port lock can block up to two ports. These ports are the inserted port, and the port directly to either side depending on the blocking plate direction. USB Port Lock can be purchased with a collar that protects attached USB Mice and Keyboards from removal without prior approval.

4.24.2 Technical Capabilities Provided by Solution

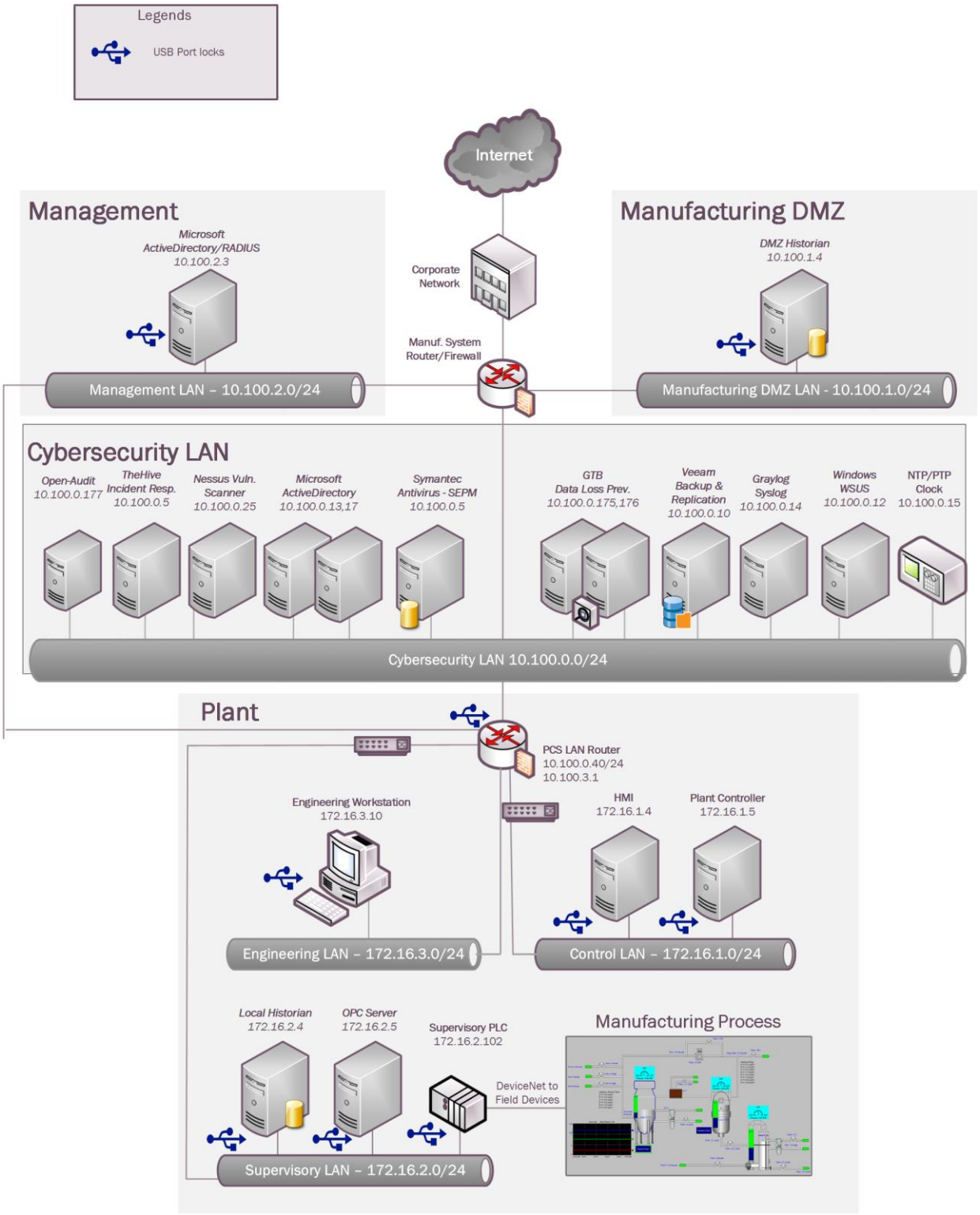
Media Protection provides components of the following Technical Capabilities described in Section 6 of Volume 1:

- Media Protection

4.24.3 Subcategories Addressed by Implementation

PR.PT-2

4.24.4 Architecture Map of Where Solution was Implemented



4.24.5 Installation Instructions and Configurations

Insert USB Port lock then push locking button in to secure. Kensington provides inserts to block multiple ports including locks designed for securing USB Keyboards and Mice.

Patience is required when using this product so as not to inadvertently damage the USB port.

4.24.6 Highlighted Performance Impacts

No performance measurement experiments were performed for the USB port locks due to their implementation method (i.e., physically restricting access to USB ports).

4.24.7 Links to Entire Performance Measurement Data Set

N/A

Appendix A - Acronyms and Abbreviations

Selected acronyms and abbreviations used in this document are defined below.

AAA	Authentication, Authorization, and Accounting
ACL	Access Control List
AD	Active Directory
API	Application Programming Interface
ARP	Address Resolution Protocol
AV	Anti-Virus
CCN	Credit Card Number
CD	Compact Disk
CEO	Chief Executive Officer
COTS	Commercial Off-The-Shelf
CSET	Cyber Security Evaluation Tool
CSF	Cybersecurity Framework
DC	Domain Controller
DCS	Distributed Control System
DHCP	Dynamic Host Configuration Protocol
DHS	Department of Homeland Security
DLP	Data Loss Prevention
DMZ	Demilitarized Zone
DNS	Domain Name System
DS	Domain Services
EFS	Encrypted File System
FIPS	Federal Information Processing Standards
FTP	File Transfer Protocol
GID	Generator ID
HIDS	Host Intrusion Detection System
HMI	Human Machine Interface
HR	Human Resources
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
HVAC	Heating, Ventilation, and Air Conditioning
ICMP	Internet Control Message Protocol
ICS	Industrial Control System
ICS-CERT	Industrial Control Systems Cyber Emergency Response Team
ICSJWG	Industrial Control System Joint Working Group
IDE	Integrated Drive Electronics

IDS	Intrusion Detection System
IEEE	Institute of Electrical and Electronics Engineers
IG	Implementation Guide
IP	Internet Protocol
ISA	The International Society of Automation
ISE	Identity Services Engine
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
LAN	Local Area Network
LDAP	Lightweight Directory Access Protocol
LDAPS	Secure LDAP
MAC	Media Access Control
MFG	Manufacturing
MGMT	Management
NAT	Network Address Translation
NCCIC	National Cybersecurity and Communications Integration Center
NETBIOS	Network Basic Input/Output System
NIDS	Network Intrusion Detection System
NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards and Technology Internal Report
NPS	Network Policy Server
NSA	National Security Agency
NTFS	New Technology File System
NTP	Network Time Protocol
NVD	National Vulnerability Database
OPC	Open Platform Communications
OS	Operating System
OSSEC	Open Source HIDS SECurity
OT	Operational Technology
PC	Personal Computer
PCS	Process Control System
PLC	Programmable Logic Controller
PPD	Presidential Policy Directive
PPP	Point to Point protocol
PPTP	Point to Point tunneling protocol
PTP	Precision Time Protocol
RDP	Remote Desktop Protocol
SCADA	Supervisory Control and Data Acquisition

SDLC	System Development Lifecycle
SEC	Security
SEPM	Symantec End-Point Protection Manager
SID	Signature ID
SIEM	Security Information and Event Management
SMB	Server Message Block
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
SSH	Secure Shell
SSL	Secure Socket Layer
SSN	Social Security Number
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UAC	User Access Control
UI	User Interface
UNC	Universal Naming Convention
UPN	Universal Principal Name
UPS	Uninterruptable Power Supply
USB	Universal Serial Bus
US-CERT	United States Computer Emergency Readiness Team
VHD	Virtual Hard Drive
VHDX	Hyper-V virtual hard disk
VLAN	Virtual Local Area Network
VPN	Virtual Private Network
WAN	Wide Area Network
WMI	Windows Management Instrumentation
XML	eXtensible Markup Language

Appendix B - Glossary

Selected terms used in in this document are defined below.

Business/Mission Objectives - Broad expression of business goals. Specified target outcome for business operations.

Capacity Planning - Systematic determination of resource requirements for the projected output, over a specific period. [businessdictionary.com]

Category - The subdivision of a Function into groups of cybersecurity outcomes closely tied to programmatic needs and particular activities.

Critical Infrastructure - Essential services and related assets that underpin American society and serve as the backbone of the nation's economy, security, and health. [DHS]

Criticality Reviews - A determination of the ranking and priority of manufacturing system components, services, processes, and inputs in order to establish operational thresholds and recovery objectives.

Critical Services - The subset of mission essential services required to conduct manufacturing operations. Function or capability that is required to maintain health, safety, the environment and availability for the equipment under control. [62443]

Cyber Risk - Risk of financial loss, operational disruption, or damage, from the failure of the digital technologies employed for informational and/or operational functions introduced to a manufacturing system via electronic means from the unauthorized access, use, disclosure, disruption, modification, or destruction of the manufacturing system.

Cybersecurity - The process of protecting information by preventing, detecting, and responding to attacks. [CSF]

Defense-in-depth - The application of multiple countermeasures in a layered or stepwise manner to achieve security objectives. The methodology involves layering heterogeneous security technologies in the common attack vectors to ensure that attacks missed by one technology are caught by another. [62443 1-1]

Event - Any observable occurrence on a manufacturing system. Events can include cybersecurity changes that may have an impact on manufacturing operations (including mission, capabilities, or reputation). [CSF]

Firmware - Software program or set of instructions programmed on the flash ROM of a hardware device. It provides the necessary instructions for how the device communicates with the other computer hardware. [Techterms.com]

Framework - The Cybersecurity Framework developed for defining protection of critical infrastructure. It provides a common language for understanding, managing, and expressing cybersecurity risk both internally and externally. Includes activities to achieve specific cybersecurity outcomes, and references examples of guidance to achieve those outcomes.

Function - Primary unit within the Cybersecurity Framework. Exhibits basic cybersecurity activities at their highest level.

Incident - An occurrence that actually or potentially jeopardizes the confidentiality, integrity, or availability of an information system or the information the system processes, stores, or transmits or that constitutes a violation or imminent threat of violation of security policies, security procedures, or acceptable use policies. [CSF]

Integrator - A value-added engineering organization that focuses on industrial control and information systems, manufacturing execution systems, and plant automation, that has application knowledge and technical expertise, and provides an integrated solution to an engineering problem. This solution includes final project engineering, documentation, procurement of hardware, development of custom software, installation, testing, and commissioning. [CSIA.com]

Manufacturing Operations - Activities concerning the facility operation, system processes, materials input/output, maintenance, supply and distribution, health, and safety, emergency response, human resources, security, information technology and other contributing measures to the manufacturing enterprise.

Network Access - any access across a network connection in lieu of local access (i.e., user being physically present at the device).

Operational technology - Hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise. [Gartner.com]

Programmable Logic Controller - A solid-state control system that has a user-programmable memory for storing instructions for the purpose of implementing specific functions such as I/O control, logic, timing, counting, three mode (PID) control, communication, arithmetic, and data and file processing. [800-82]

Profile - A representation of the outcomes that a particular system or organization has selected from the Framework Categories and Subcategories. [CSF]

- Target Profile - the desired outcome or 'to be' state of cybersecurity implementation
- Current Profile – the 'as is' state of system cybersecurity

Protocol - A set of rules (i.e., formats and procedures) to implement and control some type of association (e.g., communication) between systems. [800-82]

Remote Access - Access by users (or information systems) communicating external to an information system security perimeter. Network access is any access across a network connection in lieu of local access (i.e., user being physically present at the device). [800-53]

Resilience Requirements - The business-driven availability and reliability characteristics for the manufacturing system that specify recovery tolerances from disruptions and major incidents.

Risk Assessment - The process of identifying risks to agency operations (including mission, functions, image, or reputation), agency assets, or individuals by determining the probability of occurrence, the resulting impact, and additional security controls that would mitigate this impact. Part of risk management, synonymous with risk analysis. Incorporates threat and vulnerability analyses. [800-82]

Risk Tolerance - The level of risk that the Manufacturer is willing to accept in pursuit of strategic goals and objectives. [800-53]

Router - A computer that is a gateway between two networks at OSI layer 3 and that relays and directs data packets through that inter-network. The most common form of router operates on IP packets. [800-82]

Security Control - The management, operational, and technical controls (i.e., safeguards or countermeasures) prescribed for a system to protect the confidentiality, integrity, and availability of the system, its components, processes, and data. [800-82]

Subcategory - The subdivision of a Category into specific outcomes of technical and/or management activities. Examples of Subcategories include "External information systems are catalogued," "Data-at-rest is protected," and "Notifications from detection systems are investigated." [CSF]

Supporting Services - Providers of external system services to the manufacturer through a variety of consumer-producer relationships including but not limited to: joint ventures; business partnerships; outsourcing arrangements (i.e., through contracts, interagency agreements, lines of business arrangements); licensing agreements; and/or supply chain exchanges. Supporting services include, for example, Telecommunications, engineering services, power, water, software, tech support, and security. [800-53]

Switch - A device that channels incoming data from any of multiple input ports to the specific output port that will take the data toward its intended destination. [Whatis.com]

System Categorization - The characterization of a manufacturing system, its components, and operations, based on an assessment of the potential impact that a loss of availability, integrity, or confidentiality would have on organizational operations, organizational assets, or individuals. [FIPS 199]

Third-Party Relationships - relationships with external entities. External entities may include, for example, service providers, vendors, supply-side partners, demand-side partners, alliances,

consortiums, and investors, and may include both contractual and non-contractual parties. [DHS]

Third-party Providers - Service providers, integrators, vendors, telecommunications, and infrastructure support that are external to the organization that operates the manufacturing system.

Thresholds - Values used to establish concrete decision points and operational control limits to trigger management action and response escalation.

Appendix C - References

1. Executive Order no. 13636, Improving Critical Infrastructure Cybersecurity, DCPD-201300091, February 12, 2013. https://www.govinfo.gov/app/details/FR-2013-02-19/2013-03915

2. National Institute of Standards and Technology (2014) Framework for Improving Critical Infrastructure Cybersecurity, Version 1.0. (National Institute of Standards and Technology, Gaithersburg, MD), February 12, 2014. https://doi.org/10.6028/NIST.CSWP.02122014

3. Stouffer KA, Lightman S, Pillitteri VY, Abrams M, Hahn A (2015) Guide to Industrial Control Systems (ICS) Security. (National Institute of Standards and Technology, Gaithersburg, MD), NIST Special Publication (SP) 800-82, Rev. 2. https://doi.org/10.6028/NIST.SP.800-82r2

4. Stouffer K, Zimmerman T, Tang CY, Lubell J, Cichonski J, McCarthy J (2019) Cybersecurity Framework Manufacturing Profile. (National Institute of Standards and Technology, Gaithersburg, MD), NIST Internal Report (NISTIR) 8183, Includes updates as of May 20, 2019. https://doi.org/10.6028/NIST.IR.8183