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MORE SITUATIONAL AWARENESS FOR INDUSTRIAL CONTROL SYSTEMS (MOSAICS) BLOCK 1 INTEGRATION SPECIFICATION

Version 1.0

Prepared for: Naval Facilities Engineering Systems Command (NAVFAC)

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1. INTRODUCTION

1.1 Background

More Situational Awareness for Industrial Control Systems (MOSAICS) is a Department of Defense (DoD) effort to modernize the detection and response to threats to Industrial Control Systems (ICS). It represents the first-ever comprehensive, integrated, and automated cyber defense capability for ICS, allowing system operators (users) to quickly, easily, and effectively detect and characterize cyberattacks in near-real time. By modeling the prescriptive approach in the DoD's Advanced Cyber Industrial Control System Tactics, Techniques, and Procedures (ACI TTP)[1] document and applying Information Technology (IT) automation principles, MOSAICS effectively advances the scale and speed in identifying, investigating, and responding to incidents within the ICS system.

1.2 Purpose and Scope

This document provides the requirements for Block 1 MOSAICS. Block 2 will be addressed in a future specification. This document covers the functional and technical MOSAICS requirements as they apply to the system, deployment considerations and additional technical implementation details. This information is intended to be used by those deploying MOSAICS Block 1 capabilities to assist in identifying compatible technical solutions and integrating those solutions into a viable MOSAICS implementation. This specification is for broad use across government and commercial organizations; therefore, no specific policy guidance is provided. Implementing organizations are expected to follow their applicable guidance. Additionally, it is expected that organizations would establish a governance body to address their unique organizational roles and responsibilities, establish/update policies as required and define procedures for the operation and sustainment of the implemented MOSAICS solution.

To date, implementations of the MOSAICS framework have been limited to operational Facility Related Control Systems (FRCS) such as power distribution, building automation and water treatment systems. However, it is believed that the framework is applicable to a wider set of controls systems beyond FRCS alone; therefore, the more generic term of ICS is used throughout this specification. The ability to implement on non-FRCS may require a different suite of technologies but the functions, requirements and architecture for Block 1 would remain the same.

This is a living document that will be supplemented with additional information in the future.

[1] https://www.acq.osd.mil/eie/Downloads/IE/ACI%20TTP%20for%20DoD%20ICS_Rev_2_(Final).pdf

2. MOSAICS OVERVIEW

2.1 MOSAICS Framework Overview

MOSAICS provides a framework that defines a body of functions and requirements for control system cyber threat defense; those functions and requirements are organized into blocks. MOSAICS Block 1 allows organizations to achieve continuous passive and safe active monitoring of control system network assets. MOSAICS provides a single data repository for continuous collection of host event data, network intrusion detection alerts, network equipment logs, and network flow metrics for performing correlative analytics. MOSAICS Block 1 provides basic workflow management (See Appendix A for details) of a system baseline and on-demand integrity checking of control system assets against a stored system baseline. The MOSAICS framework has the following characteristics:

- Vendor-agnostic architecture
- Behavior-based correlative analytics
- Signature-based detection and alerting
- Intelligent automation
- Operator (user)-focused cyber visualizations

Implementation of Block 1 functionality can be done in a phased approach, initially focusing on the passive monitoring capabilities of Block 1A and then expanding into safe active monitoring capabilities of Block 1B when ready. This approach is a valuable way to build trust in the MOSAICS implementation and to ensure there is no negative impact to the control system under protection.

2.2 Block and Sub-Block Definitions

A MOSAICS capability is an implemented instantiation of the MOSAICS framework. MOSAICS capabilities are presented in terms of Blocks and Sub-blocks (Table 2-1).

Table 2-1. MOSAICS Blocks and Sub-blocks

Block	Sub-Block	Description	Capabilities
1	A*	Continuous passive monitoring of control system network and assets into a single data repository performing correlative analytics. Continuous collection of host event data, network intrusion detection alerts, network equipment logs, and network flow metrics.	- Aggregated asset inventory - Host monitoring - Network monitoring - Single aggregated event data repository - Behavioral aggregation analytics - Behavioral set correlation analytics - Visualization of events, alerts, and incidents
1	B*	Includes all functionality from Block 1A. Safe active enumeration of control system network and assets. Workflow management of a system baseline and on-demand integrity checking of control system assets against stored system baseline.	- All Block 1A Capabilities - Safe active enumeration of assets - Integrated system baseline creation - Automated workflow management for baseline creation and alert investigation - Host investigation with integrity checks
2	A	Includes all functionality from Block 1B. Workflow management of a system baseline and on-demand integrity checking of control system assets against stored system baseline. Automated generation of recommended courses of action, with automated execution of user-selected mitigations.	- All Block 1B Capabilities - Workflow automation for course-of-action suggestion - User-selected mitigation - Automated execution of user-selected mitigation actions
2	B	Includes all functionality from Block 2A. Bi-directional threat intelligence sharing between MOSAICS systems.	- All Block 2A Capabilities - Automated sharing of incident and mitigation details - Automated consumption and use of threat intelligence data
2	C	All functionality from Block 2B. Fine-grained response actions with follow-up recovery actions.	- All Block 2B Capabilities - Automated implementation of granular response actions - Automated execution of recovery actions

*Covered in this document

2.3 Functions and Block Alignment

The MOSAICS requirements were developed around seven functional capabilities: detection, analysis, visualization, decision-making, mitigation, recovery, and information sharing (Figure 2-1).

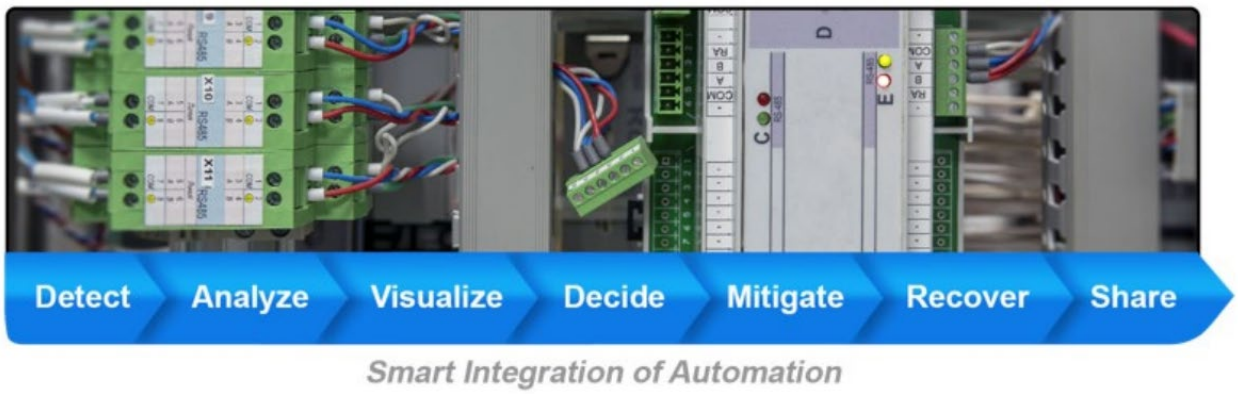


Figure 2-1. MOSAICS Functional Capabilities

The MOSAICS functions are shown in Table 2-2 with the associated functional capability and Block(s) in which each function is first implemented. Block 1A and 1B requirements are delineated in Section 4 and include the block number for each individual requirement. Block 2 requirements, and future requirements in development, will be included in a future specification. In certain cases, additional requirements for a particular MOSAICS function may be implemented in subsequent blocks (see for example, MOSAICS System Identification, and two of the MOSAICS Visualization functions).

Table 2-2. MOSAICS Functions, Functional Capabilities, and Blocks

MOSAICS Function	Functional Capability**	Block 1A	Block 1B	Block 2A	Block 2B
MOSAICS System Identification*	Detect****				
Detect and Collect Asset Information		x	x		
Assign Asset Criticality		x			
Maintain Inventory		x			
Create Baselines		x			
MOSAICS System Protection	Protect***				
Identity and Access Management		x			
Data Security		x			
Audit Logging		x			
MOSAICS Monitor and Detection	Detect				
Continuous Monitoring		x			
Detection		x			
Event Generation		x			
MOSAICS Analysis	Analyze				
Analyze Events		x			
Perform Integrity Checks			x		
MOSAICS Visualization*	Visualize				
Detected Event Visualization		x		x	
Protected Enclave Status Visualization		x			
Alert Visualization and Management		x	x	x	
Orchestration and Metric Visualization			x		
MOSAICS Decision	Decide				
Event / Incident Response Analysis				x	
MOSAICS Mitigation	Mitigate				
Event / Incident Response Execution				x	
Implement ACI TTP				x	
MOSAICS Recovery					

MOSAICS Function	Functional Capability**	Block 1A	Block 1B	Block 2A	Block 2B
Recovery Planning	Recover				x
Recovery Forensic					x
Recovery Execution					x
Recovery Verification					x
MOSAICS Information Sharing	Share				
Event / Incident Communication				x	
Threat Information Communication					x
Facility ICS / MOSAICS Status Communication				x	

*The majority of the requirements are Block 1 and are therefore covered in this document. There are additional requirements in Block 2.

**See Figure 2-1.

*** These are protection requirements for MOSAICS and the control system data residing within MOSAICS.

**** MOSAICS System Identification also covers NIST Cybersecurity Framework “Identify”.

3. MOSAICS BLOCK 1 SYSTEM OVERVIEW

A brief description of MOSAICS Block 1 functions is provided in Table 3-1 and a functional block diagram is shown in Figure 3-1.

Table 3-1. MOSAICS Function Descriptions

System Identification Requirements	Identifies assets on the network using passive network monitoring and safe active device interrogation. Maintains asset inventories. Creates baselines used in the Analysis function.
System Protection Requirements	Provides access management, data security, and audit logging for MOSAICS.
Monitor & Detection Requirements	Monitors the assets and network behavior and detects anomalous component and communication status and activity.
Analysis Requirements	Correlates events, generates alerts, and performs integrity checks.
Visualization Requirements	Provides for visualization of events, alerts, and management of alerts, as well as display of orchestrator metrics.

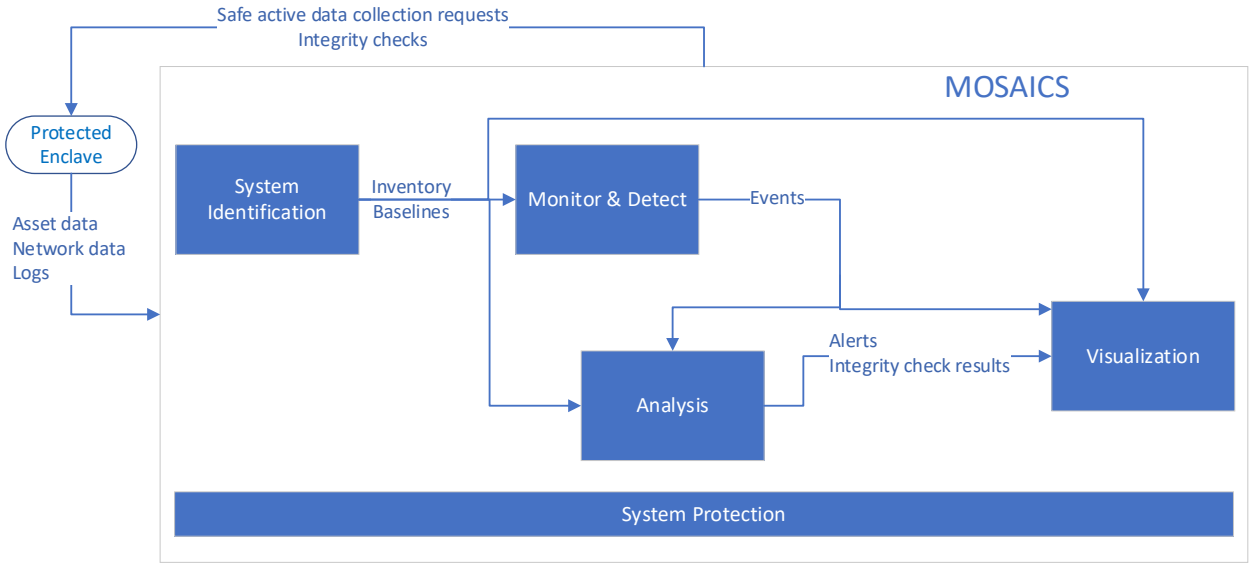


Figure 3-1. MOSAICS Functional Block Diagram

3.1 Function Descriptions

Each function is described in further detail in this section. Key concepts, noted in bold in the function descriptions, are included in the MOSAICS reference architecture in Section 3.2, Figure 3-7.

3.1.1 System Identification

Block 1 MOSAICS System Identification (F1.0) sub-functions are shown in Figure 3-2. Assets are detected on the network and information about them is collected (F1.1). The detection and collection of information is performed through **Passive Network Monitoring** and **Safe Active Device Interrogation.** The user may assign criticality to the asset (F1.2). Inventories of the control equipment, hosts, and network equipment are maintained (F1.3). Baselines are created for use in the Analysis function to perform integrity checks (F1.4).

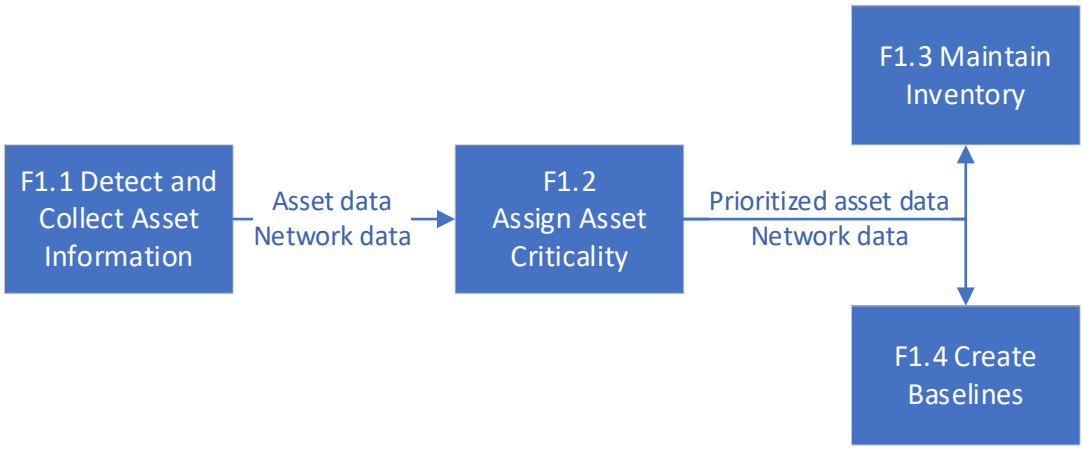


Figure 3-2. MOSAICS Block 1 System Identification Functional Block Diagram

3.1.2 System Protection Requirements

System Protection involves the protection of MOSAICS itself rather than protection of enclave assets. MOSAICS Block 1 System Protection (F2.0) sub-functions are shown in Figure 3-3 and are focused on the protection of, and access to, ICS data collected and contained within MOSAICS. MOSAICS obtains user information from facility authoritative sources and uses that information to provide access control. MOSAICS protects control system data contained within MOSAICS through encryption while at rest and in transit. MOSAICS generates audit logs for MOSAICS activities.

Application of additional security controls for the protection of MOSAICS components should be done in accordance with organizational policies and/or NIST 800-53 controls. This includes but is not limited to governance, configuration management, contingency planning, physical security and supply chain risk management considerations.

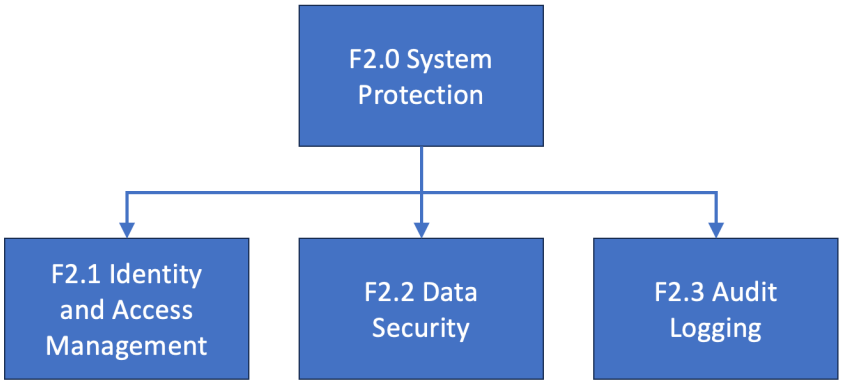


Figure 3-3. MOSAICS Block 1 System Protection Functional Block Diagram

3.1.3 Monitor & Detection Requirements

Block I MOSAICS Monitor and Detection (F3.0) sub-functions are shown in Figure 3-4. MOSAICS monitors the network communications and status of protected enclave assets and the accesses of facility protective enclave assets and systems (F3.1). MOSAICS detects changes from the baseline inventory of protective enclave assets and abnormal component behavior (F3.2) and generates an event whenever any detection criteria is triggered (F3.3). This function performs **Data Tagging & Normalization**.

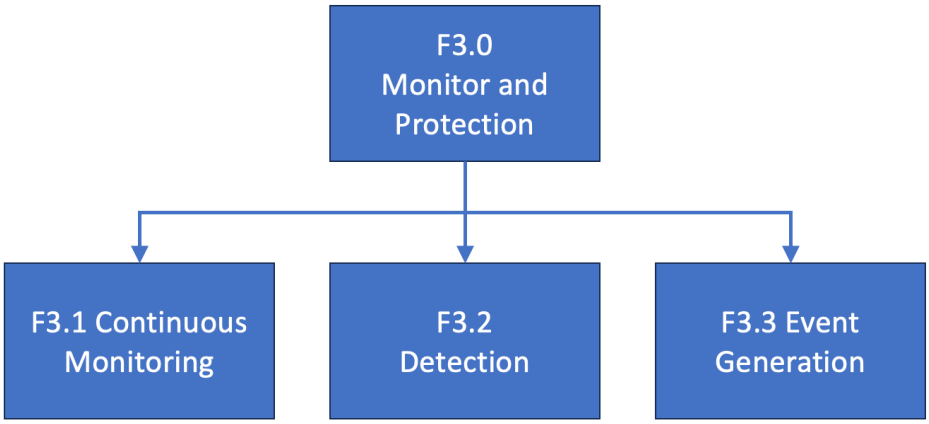


Figure 3-4. MOSAICS Block 1 Monitor and Detection Functional Block Diagram

3.1.4 Analysis Requirements

Block 1 MOSAICS Analysis (F4.0) sub-functions (**Data Analytics)** are shown in Figure 3-5. Analyze Events (F4.1) includes correlating events, assigning severity levels, and generating alerts that include relevant related information. Integrity checks which compare the current state with the baseline are also performed for each alert (F4.2). Appendix B details the Behavioral Alerting Sets for Control Systems (BAS/CS™), a Johns Hopkins University Applied Physics Laboratory (JHU/APL) Alerting Framework. An implementation of BAS/CS™ is one approach toward satisfying the MOSAICS alerting requirements. Other approaches that meet the requirements are acceptable.

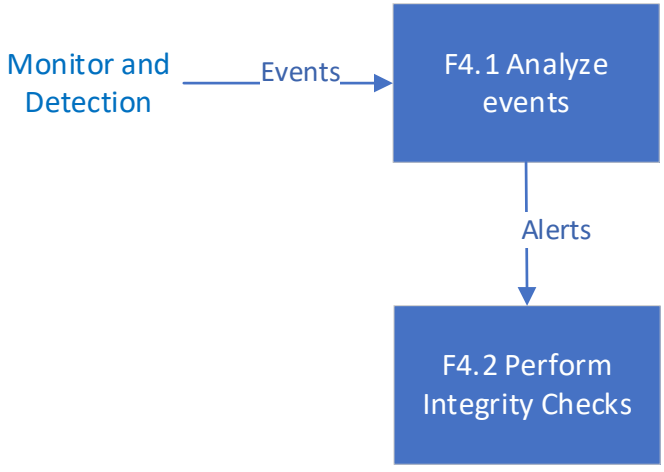


Figure 3-5. MOSAICS Block 1 Analysis Functional Block Diagram

3.1.5 Visualization

MOSAICS Block I Visualization (F5.0) sub-functions are shown in Figure 3.6. MOSAICS visualizations are a core component of providing situational awareness to the operators. Visualization enables operators to take the most informed corrective actions based on the correlative analytics of the alerts and incidents. MOSAICS accomplishes this through a three-pronged approach. It first provides a means to visualize events (F5.1). Then, MOSAICS provides visualizations for the impact of these events on the protected enclave status (F5.2). Finally, MOSAICS provides alert visualizations, alert management features for alert acknowledgement, and alert assignment in the case of a team working to resolve any incidents (F5.3). MOSAICS also provides visualizations displaying the metrics for the orchestrator, to include playbook time to completion, that enable the operator to understand how long these processes are taking (F5.4). Appendix C provides example screenshots for the implementation of MOSAICS visualization requirements.

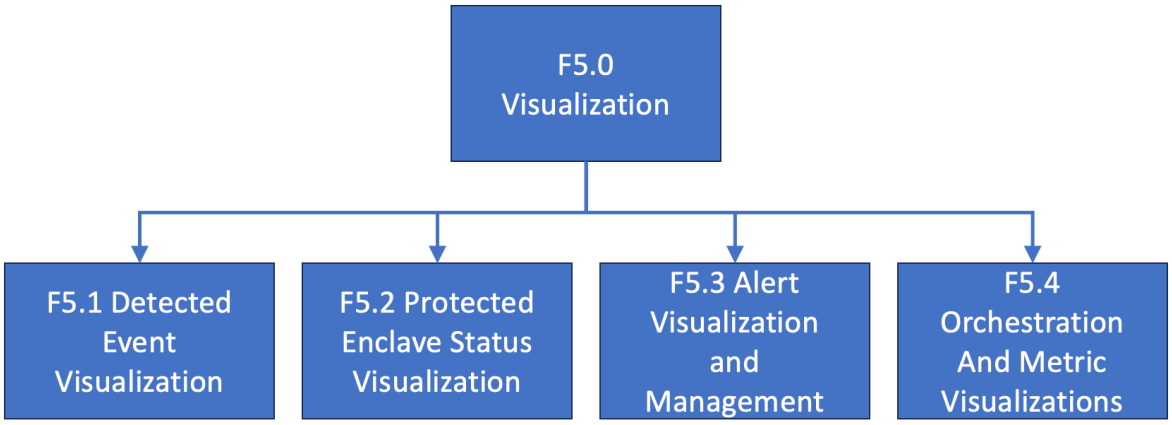


Figure 3-6. MOSAICS Block 1 Visualization Functional Block Diagram

3.2 MOSAICS Block 1 Reference Architecture

Figure 3-7 shows a reference architecture for the key MOSAICS functions identified in Section 3.1 and the Block 1 data flows.

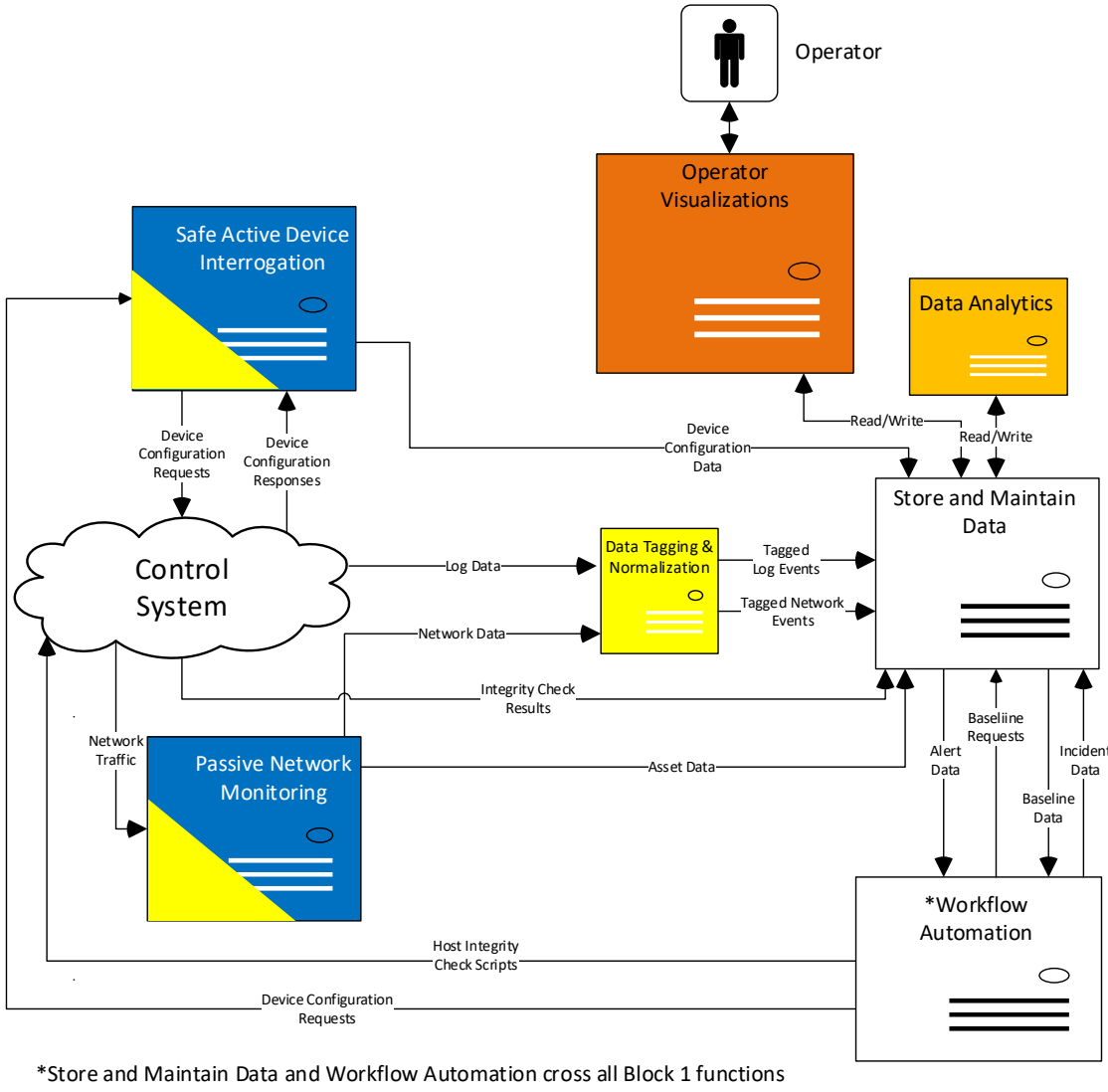


Figure 3-7. MOSAICS Block 1 Reference Architecture Data Flows

4. BLOCK 1 FUNCTIONS AND REQUIREMENTS

Functional requirements are the highest level of MOSAICS system requirements, and the technical requirements are the next-level decomposition of the functional requirements. Functional and technical requirements for each MOSAICS function are provided in the following sections.

NOTES:

The word "maintain," when used in the requirements, means to "create" and "update."

Devices within the "protected enclave" (see Section 6 Definitions) are monitored by MOSAICS. Some devices may not be actively monitored by MOSAICS (i.e., a remote site with limited connectivity, a device that speaks a different protocol, etc.).

4.1 System Identification Requirements

The System Identification Functional Requirements and Technical Requirements are provided in Table 4-1 and Table 4-2, respectively.

Table 4-1. System Identification Functional Requirements

ID	Requirement	Block
F1.0	MOSAICS System Identification Requirements	
F1.1	Detect and Collect Asset Information	
F1.1.1	MOSAICS shall detect assets on the network. *Note: Assets include host, network equipment, and control equipment.*	**1A**
F1.2	Assign Asset Criticality	
F1.2.1	MOSAICS shall provide the capability for the user to assign asset criticality. *Note: Critical assets may be those that contribute to the facility's mission or are assessed as high-value.*	**1A**
F1.3	Maintain Inventory	
F1.3.1	MOSAICS shall maintain an inventory of assets.	**1A**
F1.4	Create Baselines	
F1.4.1	MOSAICS shall maintain a baseline of assets.	**1A**

Table 4-2. System Identification Technical Requirements

Req Number	Requirement	Map to Funct Rqmts	Block
F1.0	MOSAICS System Identification Technical Requirements		
F1.1	Detect and Collect Asset Information		
	Passive Detection and Collection		
T1.1.1.1	MOSAICS shall be capable of automated, passive data collection via a local switch SPAN port or serial port.	F1.1.1	**1A**
T1.1.1.2	MOSAICS shall be capable of automated, passive data collection on control equipment that is not capable of Internet Protocol (IP) or not connected to the IP network. *Note: This could include non-IP-addressable devices communicating through intermediary devices providing native communication protocol traffic encapsulated in IP.*	F1.1.1	**1A**
T1.1.1.3	MOSAICS shall be capable of automated, passive collection of the following control equipment information, at a minimum: • IP address • Media Access Control Address (MAC address) • Vendor • Protocols used	F1.1.1	**1A**
T1.1.1.4	MOSAICS shall be capable of automated, passive collection of the following host information, at a minimum, upon user demand: • IP address • MAC address • Hostname • OS type • Protocols used	F1.1.1	**1A**
T1.1.1.5	MOSAICS shall be capable of automated, passive collection of the following network equipment information, at a minimum, upon user demand: • IP address • MAC address • Hostname • Protocols used	F1.1.1	**1A**
	Manual Data collection *Note: In this manual collection case, the user collects the information and provides it to MOSAICS to ingest.*		
T1.1.1.6	MOSAICS shall be capable of manually ingesting and processing control equipment information, upon user demand. *Note: The manually ingestible control equipment information consists of the information that can be actively collected (see T1.1.1.11) and potentially additional information such as owner, location, etc.*	F1.1.1	**1A**

Req Number	Requirement	Map to Funct Rqmts	Block
T1.1.1.7	MOSAICS shall be capable of manually ingesting and processing host information, upon user demand: *Note: The manually ingestible host information consists of the information that can be actively collected (see T1.1.1.12) and potentially additional information such as owner, location, etc.*	F1.1.1	**1A**
T1.1.1.8	MOSAICS shall be capable of manually ingesting and processing network equipment information, upon user demand: Note: The manually ingestible host information consists of the information that can be actively collected (see T1.1.1.12) and potentially additional information such as owner, location, etc.	F1.1.1	**1A**
	Safe Active Data Collection		
T1.1.1.9	MOSAICS shall be capable of automated, active data collection on control equipment that is not capable of IP or not connected to the IP network. *Note: This could include non-IP-addressable devices communicating through intermediary devices providing native communication protocol traffic encapsulated in IP.*	F1.1.1	**1B**
T1.1.1.10	MOSAICS shall be capable of automated, active collection of the following control equipment information, at a minimum: • IP address • MAC address • Vendor • Protocols used • Configuration data • Ladder logic • Logs • Software/Firmware • Hardware	F1.1.1	**1B**

Req Number	Requirement	Map to Funct Rqmts	Block
T1.1.1.11	MOSAICS shall be capable of active collection of the following host information, at a minimum: • IP address • MAC address • Hostname • OS type • OS version • Vendor • Registry entry values • User accounts • User profiles • Processes • Services • Process network connections • Installed drivers • Log entries • Peripheral devices • HOST file hash • LMHOST file hash • Alternate Data Streams (ADSs) • System Status • Memory Status	F1.1.1	**1B**
T1.1.1.12	MOSAICS shall be capable of active collection of the following network equipment information, at a minimum: • IP address • MAC address • Hostname • Vendor • Interface files • Network tables including routing tables (i.e. configuration files) • ARP tables • Dynamic Host Configuration Protocol (DHCP) server configuration files • Access control lists • Firewall or ipTables rules • Users	F1.1.1	**1B**
T1.1.1.13	MOSAICS shall store the following in a common data repository. • Inventory • Baselines *Note: This information is stored in a data repository for further investigative purposes.*	F1.1.1	**1A**

F1.2	Assign Asset Criticality		

Req Number	Requirement	Map to Funct Rqmts	Block
T1.2.1.1	MOSAICS shall provide the capability for the user to assign criticality to assets. *Note: Critical assets may be those that contribute to the facility's mission or are assessed as high-value.*	F1.2.1	**1A**
T1.2.1.2	MOSAICS shall maintain asset criticality information. *Note: This criticality information is used in T4.1.1.3 to determine alert severity and in Block 2 to prioritize responses based on threat and mission impact.*	F1.2.1	**1A**
F1.3	Maintain Inventory Note: Maintaining the inventory includes creating it and updating it.		
T1.3.1.1	MOSAICS shall maintain an inventory of control equipment. *Note: Control equipment is identified by passive or active scanning and may also be identified manually (see T1.1.1.3 T1.1.1.10, and T1.1.1.6, respectively).*	F1.3.1	**1A**
T1.3.1.2	MOSAICS shall maintain an inventory of hosts. *Note: Hosts are identified by passive or active scanning and may also be identified manually (see T1.1.1.4 T1.1.1.11, and T1.1.1.7, respectively).*	F1.3.1	**1A**
T1.3.1.3	MOSAICS shall maintain an inventory of network equipment. *Note: Network equipment is identified by passive or active scanning and may also be identified manually (see T1.1.1.5 T1.1.1.12, and T1.1.1.8, respectively).*	F1.3.1	**1A**
T1.3.1.4	MOSAICS shall uniquely identify each asset in inventory. *Note: The unique identification may be IP address, MAC address, or hostname, for example.*	F1.3.1	**1A**
T1.3.1.5	MOSAICS shall update asset inventories upon change in assets in the protected enclave. *Note: This applies to all inventories (control equipment, hosts, and network equipment).*	F1.3.1	**1A**
F1.4	Create Baselines Note: When the system is first deployed, the user will create a baseline. An asset, or all assets, may be re-baselined upon user demand. These baselines are used by the Analysis function to identify deviations from the baselines.		
T1.4.1.1	MOSAICS shall create a baseline of user accounts and associated user profiles for hosts within the protected enclave, upon user demand.	F1.4.1	**1A**
T1.4.1.2	MOSAICS shall create a baseline of network communications between control equipment, hosts, and network equipment, upon user demand.	F1.4.1	**1A**
T1.4.1.3	MOSAICS shall create a baseline of control equipment, upon user demand.	F1.4.1	**1A**
T1.4.1.4	MOSAICS shall create a baseline of hosts, upon user demand.	F1.4.1	**1A**
T1.4.1.5	MOSAICS shall create a baseline of network equipment, upon user demand.	F1.4.1	**1A**

Acronyms not defined within this table can be found in Appendix D.

4.2 System Protection Requirements

The System Protection Functional Requirements and Technical Requirements are provided in Table 4-3 and Table 4-4, respectively. Specific security requirements for a system would depend on where the framework is being implemented.

Table 4-3. System Protection Functional Requirements

ID	Requirement	Block
F2.0	MOSAICS System Protection Requirements	
F2.1	Identity and Access Management Requirements	
F2.1.1	MOSAICS shall manage access to MOSAICS, based on user identity and access permissions.	**1A**
F2.2	Data Security Requirements	
F2.2.1	MOSAICS shall protect the data collected by MOSAICS Note: Data stored must be encrypted.	**1A**
F2.3	Audit Logging Requirements	
F2.3.1	MOSAICS shall maintain audit logs for MOSAICS activities, in accordance with facility policies.	**1A**

Table 4-4. System Protection Technical Requirements

Req Number	Requirement	Map to Funct Rqmts	Block
F2.0	MOSAICS System Protection Technical Requirements		
F2.1	Identity and Access Management Technical Requirements		
T2.1.1.1	MOSAICS shall control access to MOSAICS using Role Based Access Control (RBAC). *Note: The user and authorized device information is obtained for authoritative sources (see F2.1.4). This is not meant to imply that MOSAICS has an Active Directory of its own.*	F2.1.1	**1A**
T2.1.1.2	MOSAICS shall maintain the identities, credentials, and access permissions for authorized devices and users for MOSAICS. *Note: This allows MOSAICS to integrate with facility Active Directory, for example.*	F2.1.1	**1A**
T2.1.1.3	MOSAICS shall access the identities and credentials for authorized devices and users maintained by Facility authoritative sources. *Note: This is for local accounts maintained by MOSAICS.*	F2.1.1	**1A**
F2.2	Data Security Technical Requirements		

Req Number	Requirement	Map to Funct Rqmts	Block
T2.2.1.1	MOSAICS shall protect the data collected by MOSAICS using FIPS 140-3 validated cryptography while at rest. *Note: Data stored must be encrypted.*	F2.2.1	**1A**
T2.2.1.2	MOSAICS shall protect the data in transit within the MOSAICS system using FIPS 140-3 validated cryptography, where feasible. *Note: Data must be encrypted when sent between MOSAICS system components and between control equipment and MOSAICS, where feasible. "Where feasible" is used because some communications will not support encryption.*	F2.2.1	**1A**
F2.3	Audit Logging Requirements		
T2.3.1.1	MOSAICS shall log the following activities, at a minimum: • User access to MOSAICS components • User-initiated actions • All automated workflow executions • Events and alerts • Integrity check execution • Actions performed (including provenance) • Failed actions • Errors • State at time of a service interruption or system shutdown *Note: Actions provenance includes associated information origin and decision rationale.*	F2.3.1	**1A**
T2.3.1.2	MOSAICS shall provide the ability to archive historical log data.	F2.3.1	**1A**
T2.3.1.3	MOSAICS shall provide the ability to recover previously archived historical log data.	F2.3.1	**1A**

4.3 Monitor & Detection Requirements

The Monitor & Detection Functional Requirements and Technical Requirements are provided in Table 4-5 and Table 4-6, respectively.

Table 4-5. Monitor & Detection Functional Requirements

ID	Requirement	Block
F3.0	MOSAICS Monitor and Detection Requirements	
F3.1	Continuous Monitoring Requirements	
F3.1.1	MOSAICS shall continuously monitor network communication within the protected enclave.	**1A**
F3.1.2	MOSAICS shall continuously monitor the status of protected enclave assets.	**1A**
F3.2	Detection Requirements	
F3.2.1	MOSAICS shall detect changes to the configuration of protected enclave assets.	**1A**

ID	Requirement	Block
F3.2.2	MOSAICS shall detect abnormal behavior of protected enclave assets.	**1A**
F3.2.3	MOSAICS shall detect malicious indicators on protected enclave assets.	**1A**
F3.2.4	MOSAICS shall detect changes to the configuration of protected enclave network communications.	**1A**
F3.2.5	MOSAICS shall detect abnormal behavior of the protected enclave network communications.	**1A**
F3.2.6	MOSAICS shall detect malicious indicators on the protected enclave network communications.	**1A**
F3.3	Event Generation	
F3.3.1	MOSAICS shall generate an event whenever any detection criteria (e.g., change in behavior, access/usage rule violation) not captured in the baseline is triggered.	**1A**

Table 4-6 Monitor & Detection Technical Requirements

Req Number	Requirement	Map to Funct Rqmts	Block
F3.0	MOSAICS Monitor and Detection Technical Requirements		
F3.1	Continuous Monitoring Technical Requirements		
T3.1.1	MOSAICS shall collect communication data on the protected enclave network (e.g., full-packet captures for IP-based networks)	F3.1.1	**1A**
T3.1.2	MOSAICS shall collect the following data for protected enclave control equipment assets, including at a minimum: • IP address • MAC address • Vendor • Protocols used	F3.1.2	**1A**
T3.1.3	MOSAICS shall collect the following data for protected enclave network equipment assets, including at a minimum: • IP address • MAC address • Hostname • Protocols used	F3.1.2	**1A**
T3.1.4	MOSAICS shall collect the following data for protected enclave hosts, as a minimum: • IP address • MAC address • Hostname • OS type	F3.1.2	**1A**
F3.2	Detection Requirements		

Req Number	Requirement	Map to Funct Rqmts	Block
T3.2.1	MOSAICS shall detect changes to the configuration of protected enclave control equipment assets, including at a minimum: • Reconfiguration: Firmware, Logic, settings, etc. • Connections: New or external networks	F3.2.1	**1A**
T3.2.2	MOSAICS shall detect changes in the behavior on protected enclave control equipment assets, including at a minimum: • Account actions: Add or remove privileges, unsuccessful login, etc. • Remote Access: SSH, FTP, etc.	F3.2.2	**1A**
T3.2.3	MOSAICS shall detect changes to the configuration of protected enclave network equipment assets, including at a minimum: • Reconfiguration: Firmware, Logic, settings, etc. • Connections: New or external networks	F3.2.1	**1A**
T3.2.4	MOSAICS shall detect changes in the behavior of protected enclave network equipment assets, including at a minimum: • Account actions: Add or remove, privileges, unsuccessful login, etc. • Remote Access: SSH, FTP, etc.	F3.2.2	**1A**
T3.2.5	MOSAICS shall detect changes to the configuration of protected enclave host assets, including at a minimum: • User accounts • User profiles • Processes • Services • Process network connections • Installed drivers • Log entries • Peripheral devices • Memory status • Executable file creation	F3.2.1	1A
T3.2.6	MOSAICS shall detect changes of process and service behavior of protected enclave hosts, including at a minimum: • Installation: Applications, services, tasks, etc. • Remote Access: RDP, WMI, etc. • Shell: Command prompt, PowerShell, etc. • Connections: Process reach out, external networks, shares	F3.2.2	1A
T3.2.7	MOSAICS shall detect changes of peripheral device behavior of protected enclave hosts, including at a minimum: • Peripherals: USBs, removable devices, etc.	F3.2.2	**1A**
T3.2.8	MOSAICS shall detect changes in user/account behavior of protected enclave hosts, including at a minimum: • Account actions: Add or remove, privileges, unsuccessful login, etc.	F3.2.2	**1A**
T3.2.9	MOSAICS shall detect changes in file behavior of protected enclave hosts. *Note: An executable file could start acting in an unexpected manner (unexpected memory access, for example).*	F3.2.2	**1A**

Req Number	Requirement	Map to Funct Rqmts	Block
T3.2.10	MOSAICS shall detect a malicious file signature on a protected enclave asset.	F3.2.3	**1A**
T3.2.11	MOSAICS shall detect changes in protected enclave network traffic communication configuration, including at a minimum: • Changes in protocols present • Changes in IP addresses	F3.2.4	**1A**
T3.2.12	MOSAICS shall detect anomalous protected enclave network traffic behavior, including at a minimum: • Changes in volume of network traffic • Changes in timing of network traffic	F3.2.5	**1A**
T3.2.13	MOSAICS shall detect when a malicious network traffic signature is present on the protected enclave network.	F3.2.6	**1A**
F3.3	Event Generation		
T3.3.1	MOSAICS shall store events in a common data repository. *Note: This information is stored in a data repository for further investigative purposes.*	F3.3.1	**1A**
T3.3.2	MOSAICS shall generate an event within 1 minute of the activity resulting in the event.	F3.3.1	**1A**
T3.3.3	MOSAICS shall categorize events with a normalized event tag. *Note: The tag is for use in analysis.*	F3.3.1	**1A**
T3.3.4	MOSAICS events shall include the following, at a minimum: • All accompanying data elements used to generate the event • Timestamp of when event created • Normalized event tag • Unique identifier	F3.3.1	**1A**

Acronyms not defined within this table can be found in Appendix D.

4.4 Analysis Requirements

The Analysis Functional Requirements and Technical Requirements are provided in Table 4-7 and Table 4-8, respectively.

Table 4-7. Analysis Functional Requirements

ID	Requirement	Block
F4.0	MOSAICS Analysis Requirements	
F4.1	Analyze Events	
F4.1.1	MOSAICS shall analyze events. *Note: Event analysis includes correlating events, generating alerts, and assigning severity levels.*	**1A**
F4.2	Perform Integrity Checks	

ID	Requirement	Block
F4.2.1	MOSAICS shall perform integrity checks. *Note: Integrity checks are performed when alerts are generated.*	**1B**

Table 4-8. Analysis Technical Requirements

Req Number	Requirement	Map to Funct Rqmts	Block
F4.0	MOSAICS Analysis Technical Requirements		
F4.1	Analyze Events		
T4.1.1.1	MOSAICS shall correlate events across assets, network communications, and time for analysis. *Note: Events are correlated across sensors based on relationships identified between events within a specific block of time. Time for analysis is 5 minutes, per T4.1.1.8.*	F4.1.1	**1A**
T4.1.1.2	MOSAICS shall generate an alert based on predefined threat patterns of behavior. *Note: Alerts may be based on a single event or multiple correlated events. Alerts are sent to the Visualization function for display to the user.*	F4.1.1	**1A**
T4.1.1.3	MOSAICS shall determine severity levels for alerts based on the following, at a minimum: • Number of correlated events • Integrity check results • Criticality of the asset *Note: See T1.2.1.2 for asset criticality assignment. See T4.2.1.1 for integrity checks.*	F4.1.1	**1A**
T4.1.1.4	MOSAICS shall include the following information relevant to the alert, at a minimum, when generating an alert: • The event(s) resulting in the alert • The associated assets • Alert severity • Integrity check results	F4.1.1	**1A**
T4.1.1.5	MOSAICS shall provide the user the capability to identify an alert as an incident. *Note: Alerts may be identified as an incident by a user or by MOSAICS through Artificial Intelligence/Machine Learning (AI/ML) (see T4.1.1.6).*	F4.1.1	**1A**
T4.1.1.6	MOSAICS shall identify an alert as an incident. *Note: Alerts may be identified as an incident by a user or by MOSAICS through AI/ML. (see T4.1.1.5).*	F4.1.1	**1A**
T4.1.1.7	MOSAICS shall store the following in a common data repository. • Alerts and associated information (includes integrity check results) • Incidents and associated information *Note: This information is stored in a data repository for further investigative purposes.*	F4.1.1	**1A**

Req Number	Requirement	Map to Funct Rqmts	Block
T4.1.1.8	MOSAICS shall generate alerts within 5 minutes of generation of events. *Note: This requirement drives the block of time used in T4.1.1.1.*	F4.1.1	**1A**
F4.2	Perform Integrity Checks Note: The integrity check is performed through automation by comparing observed values with baseline normal values.		
T.4.2.1.1	MOSAICS shall automatically identify required integrity checks to perform based on alert type. *Note: Integrity checks are those related to that specific alert type, and may include data for control equipment, host, or network equipment, as well as user accounts and network communications.*	F4.2.1	**1B**
T4.2.1.2	MOSAICS shall automatically collect the following control equipment information, at a minimum, when performing an integrity check: • IP address • MAC address • Vendor • Protocols used • Configuration data • Ladder logic • Logs • Software/Firmware • Hardware *Note: This is the full set of data that can be collected through active collection (see T1.1.1.10). A subset is collectable through passive collection (T1.1.1.3).*	F4.2.1	**1B**

Req Number	Requirement	Map to Funct Rqmts	Block
T4.2.1.3	MOSAICS shall automatically collect the following host information, at a minimum, when performing an integrity check: • IP address • MAC address • Hostname • OS type • OS version • Vendor • Registry entry values • User accounts • User profiles • Processes • Services • Process network connections • Installed drivers • Log entries • Peripheral devices • HOST file hash • LMHOST file hash • ADS • System Status • Memory Status *Note: This is the full set of data that can be collected through active collection (see T1.1.1.11). A subset is collectable through passive collection (T1.1.1.4).*	F4.2.1	**1B**
T4.2.1.4	MOSAICS shall automatically collect the following network equipment information, at a minimum, when performing an integrity check: • IP address • MAC address • Hostname • Vendor • Interface files • Network tables including routing tables • ARP tables • DHCP server configuration files • Access control lists • Firewall or ipTables rules • Users *Note: This is the full set of data that can be collected through active collection (see T1.1.1.12). A subset is collectable through passive collection (T1.1.1.5).*	F4.2.1	**1B**
T4.2.1.5	MOSAICS shall automatically compare data collected for integrity checks with the baseline for the data. *Note: See T.4.2.1.1 through T.4.2.1.3 for data collected. See T1.4.1.1 through T1.4.1.5 for baselines.*	F4.2.1	**1B**

Req Number	Requirement	Map to Funct Rqmts	Block
T4.2.1.6	MOSAICS shall automatically generate integrity check results that include the following, at a minimum: • Differences between data collected for integrity check and the baseline • Errors encountered when performing the integrity check *Note: Integrity check results are used when determining alert severity (see T4.1.1.3) and are provided with generated alerts (see T4.1.1.4).*	F4.2.1	**1B**
T4.2.1.6	MOSAICS shall complete integrity checks within 15 minutes of alert generation.	F4.2.1	**1B**

4.5 Visualization

The Visualization Functional Requirements and Technical Requirements are provided in Table 4-9 and Table 4-10, respectively.

Table 4-9. Visualization Functional Requirements

ID	Requirement	Block
F5.0	MOSAICS Visualization Requirements	
F5.1	Detected Event Visualization Requirements	
F5.1.1	MOSAICS shall provide the capability to visualize detected events.	**1A**
F5.2	Protected Enclave Status Visualization Requirements	
F5.2.1	MOSAICS shall provide the capability to visualize the protected enclave status.	**1A**
F5.3	Alert Visualization and Management Requirements	
F5.3.1	MOSAICS shall provide the capability to manage alerts.	**1B**
F5.3.2	MOSAICS shall provide the capability to visualize alerts.	**1A**
F5.4	Orchestration and Metric Visualization Requirements	
F5.4.1	MOSAICS shall provide the capability to visualize performance metrics related to Orchestration.	**1B**

Table 4-10. Visualization Technical Requirements

Req Number	Requirement	Map to Funct Rqmts	Block
F5.0	MOSAICS Visualization Technical Requirements		
F5.1	Detected Event Visualization Technical Requirements		
T5.1.1.1	MOSAICS shall allow a user to perform searches on event data.	F5.1.1	**1A**
T5.1.1.2	MOSAICS shall allow a user to perform sorts on event data.	F5.1.1	**1A**
T5.1.1.3	MOSAICS shall allow a user to perform filtering on event data.	F5.1.1	**1A**
T5.1.1.4	MOSAICS shall perform trending and charting of event data.	F5.1.1	**1A**
F5.2	Protected Enclave Status Visualization Technical Requirements		
T5.2.1.1	MOSAICS shall allow the user to view logs, events, and alerts.	F5.2.1	**1A**
T5.2.1.2	MOSAICS shall provide the capability to display which asset of the protected enclave has been affected by alerts and events.	F5.2.1	**1A**

Req Number	Requirement	Map to Funct Rqmts	Block
T5.2.1.3	MOSAICS shall provide the capability to display device identifying properties of devices monitored by MOSAICS. At a minimum this will include: • IP address • MAC address • Device model • Device serial number • Property owners • Internal property number	F5.2.1	**1A**
T5.2.1.4	MOSAICS shall provide the capability to display the user accounts logged into assets monitored by MOSAICS. Note: This includes both network and host assets.	F5.2.1	**1A**
T5.2.1.5	MOSAICS shall provide the capability to display the current communication protocols used by an asset monitored by MOSAICS.	F5.2.1	**1A**
T5.2.1.6	MOSAICS shall display a page that is dedicated to displaying the health and status of specific assets. Note: This includes problematic credentials on network and host assets.	F5.2.1	**1A**
T5.2.1.7	MOSAICS shall provide the capability to visualize baseline information for each asset. *Note: The assets include control equipment, hosts, and network equipment.*	F5.2.1	**1A**
T5.2.1.8	MOSAICS shall provide the capability to visualize a current map of network communication flows between control equipment, hosts, and network devices. *Note: This map is generated from live network communication.*	F5.2.1	**1A**
F5.3	Alert Visualization and Management Technical Requirements		
T5.3.1.1	MOSAICS shall provide the capability for the user to acknowledge displayed alerts.	F5.3.1	**1B**
T5.3.1.2	MOSAICS shall provide the capability to assign alerts.	F5.3.1	**1B**
T5.3.1.3	MOSAICS shall provide the capability to open/close alerts.	F5.3.1	**1B**
T5.3.2.1	MOSAICS shall have the capability to visualize any alert.	F5.3.2	**1A**
T5.3.2.2	MOSAICS shall have the capability to see correlated events for a given alert.	F5.3.2	**1A**
T5.3.2.3	MOSAICS shall have the capability to visualize incidents.	F5.3.2	**1A**

Req Number	Requirement	Map to Funct Rqmts	Block
T5.3.2.4	MOSAICS shall provide the ability to search, sort, and filter alerts by data attributes, which at a minimum will include: • IP addresses • MAC addresses • Device serial numbers • Property owners • Device models • Logins • Process IDs • Priority • Date/time • Severity	F5.3.2	**1A**
T5.3.2.5	MOSAICS shall provide the ability to display all integrity checks triggered by an alert.	F5.3.2	**1B**
T5.3.2.6	MOSAICS shall display the results of integrity checks triggered by an alert within 5 seconds of completion of the integrity check. *Note: The results of the integrity checks include errors encountered by the integrity checks if they failed for any reason.*	F5.3.2	**1B**
T5.3.2.7	MOSAICS shall perform trending and charting of alert/incident data.	F5.3.2	**1A**
F5.4	Orchestration and Metric Visualization Requirements		
T5.4.2.1	MOSAICS shall provide visualizations capable of displaying metrics regarding the state of the orchestrator.	F5.4.2	**1B**
T5.4.2.2	MOSAICS shall provide visualizations capable of displaying metrics regarding playbook time to completion.	F5.4.2	**1B**
T5.4.2.3	MOSAICS shall display an alert within 5 seconds of alert generation.	F5.4.2	**1A**

Acronyms not defined within this table can be found in Appendix D.

5. DEPLOYMENT CONSIDERATIONS

The following should be considered when deploying MOSAICS:
Shared Goals and Objectives: It is important to socialize ideas across the organization in order to drive interest, support, and commitment. Ensuring a shared understanding of the threat, the need for improved operational technology (OT) cybersecurity, and the goals and objectives with the implementation of MOSAICS is essential to acceptance of these capabilities.

Build Trust: Building trust in the use of MOSAICS and developing confidence that MOSAICS does not pose a risk to operations is essential. Implementing the passive monitoring capabilities defined in MOSAICS Block 1A, expanding into safe active monitoring capabilities of Block 1B, and maturing the capabilities with Block 2 concepts are great ways to demonstrate value and build trust over time.

Product Integration: When selecting capabilities for the control system environment, consider implications for the ability to automate data collection and investigation processes. The right functionality must be exposed through Application Programming Interfaces (API) in order to gain efficiencies via automation and to leverage new capabilities in operations.

Sustainment: Consider long-term sustainment of the MOSAICS capabilities up front. As new sensors or data sources are added to the environment, organizations must ensure they have the skills required to integrate new products, incorporate new alerts, and build visualization dashboards for improved operational efficiency.

Asset Discovery and Enumeration: Limitations exist in the amount of detailed data that can be obtained through the passive discovery means defined in Block 1A. Safe active enumeration techniques (Block 1B) provide the capability to monitor and alert on changes to the environment at a much more granular level and are considered essential to full Block 1 implementation.

OT Technology Enumeration: Matching a discovery and enumeration capability to the control system for which it will be used is vital to ensuring the most effective solution. Some products are found to be simply better at identifying and enumerating specific control system technologies than others. This is especially true when utilizing active enumeration techniques because the interfaces need to be designed for specific vendor technologies. However, this can also be seen when simply parsing passive network traffic, and thus it is critical to understand what control system technologies are supported by a vendor prior to acquisition.

Data Ingestion: The ability to consume and correlate data from sensors deployed across all layers of an ICS architecture is vital for robust threat detection. Interfaces specifically for ICS sensors and data are lacking in comparison to IT tools; therefore, the ability to develop custom plug-ins or connectors ensures that relevant data can be made available for analysis.

Alerting and Correlation: Adversaries often adapt their tactics and techniques to the environment they are attacking. While some threat activity will always occur prior to other events, it is essential that a threat be detected, regardless of the sequential order in which these events occur. The ability to support non-sequential event correlation for detection and alerting is a critical component for

the selected analytic platform. This ensures that a minor change in adversary tactics will not result in missing threat activity.

Operational Availability: MOSAICS operational availability will be determined by the facility owner. MOSAICS must not degrade the operational availability of the control equipment, network equipment, or hosts (i.e., Do no harm) and not adversely impact other connected systems (e.g., Control System Platform Enclave).

6. DEFINITIONS

Term	Definition
Alerts	Notifications of event(s) that need operator attention. Alerts may be based on a single event or multiple correlated events.
Asset	Physical or logical object owned or under custodial duties of an organization (ISA-62443) All assets referred to are either host, network equipment, or control equipment.
Control Equipment	Asset: Class that includes distributed control systems (DCSs), programmable logic controllers (PLCs), supervisory control and data acquisition (SCADA) systems, associated operators interface consoles, and field sensing and control devices used to manage and control the process (ISA-62443)
Protected Enclave	A set of system resources that operate in the same security domain and share the protection of a single, common, continuous security perimeter, monitored and protected by the MOSAICS System.
Events	An event is a captured change in the environment, including low-level occurrences (MS Windows log events, Intrusion Detection System (IDS) events, for example).
Host	Asset: Physical or logical computer that is attached to a communication subnetwork or inter-network and can use services provided by the network to exchange data with another attached system (ISA-62443).
Incident	An alert that requires an action. Operators may make the determination that an alert is an incident. An AI/ML function could also potentially make this determination in MOSAICS.
Industrial Control System (ICS)	A general term that encompasses several types of control systems, including SCADA systems, DCSs, and other control system configurations such as PLCs, often found in industrial sectors and critical infrastructures. An ICS consists of combinations of control components (e.g., electrical, mechanical, hydraulic, pneumatic) that act together to achieve an industrial objective (e.g., manufacturing, transportation of matter or energy).
Integrity Check	Identifies deviations from the baseline.
MOSAICS Capability	Implemented instantiation of the MOSAICS framework. A collection of integrated technologies which satisfy, at a minimum, MOSAICS Block 1A.
MOSAICS Framework	A framework defining a body of functions and requirements for control system cyber threat defense organized into blocks.
Network Communication	The process of exchanging information between two or more devices connected to a network. This includes IP- and non-IP-based communications.
Network Equipment	Asset: Class that includes switches, routers, firewalls, gateways, and media converters used to manage and control the network communications.
Network Traffic	Computer network communications that are carried over wired or wireless networks between hosts.
Safe Active Enumeration	Uses the native protocols of the device so as not to negatively impact the device.

7. REFERENCES

1. Advanced Cyber Industrial Control System Tactics, Techniques, and Procedures (ACI TTP) for Department of Defense (DoD) Industrial Control Systems (ICS), Revision 2, March 2018

2. More Situational Awareness for ICS (MOSAICS) Analysis of Alternatives, Johns Hopkins University Applied Physics Laboratory, AOS-23-0207, 14 February 2023

3. MOSAICS Final Report, Johns Hopkins University Applied Physics Laboratory, AOS-20-1416, October 2020

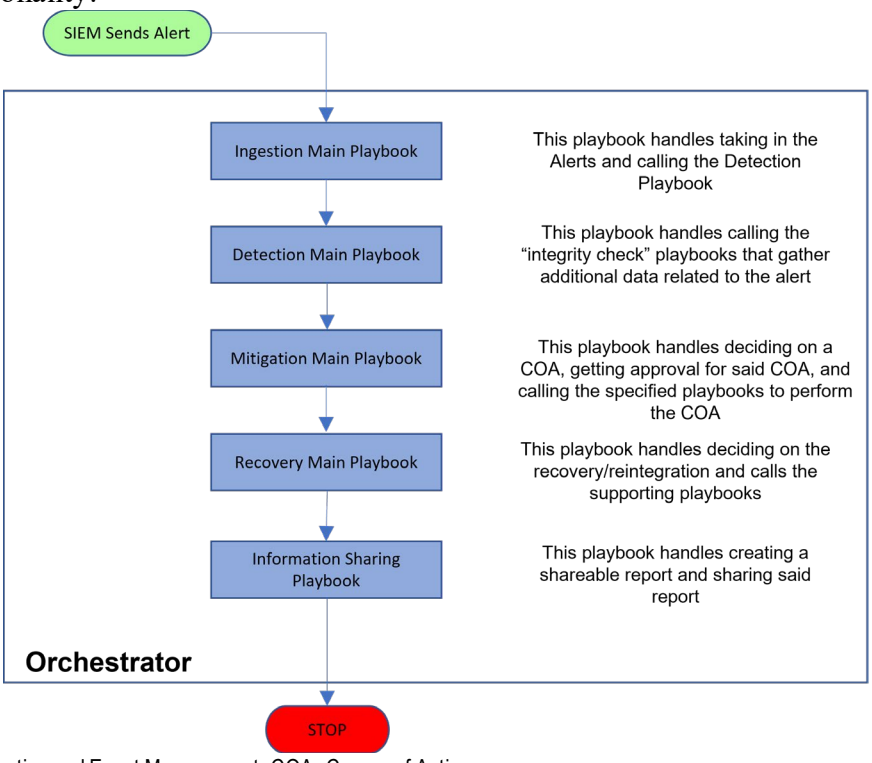
4. NIST FIPS 140-3, "Security Requirements for Cryptographic Modules, Information Technology Laboratory NIST," 22 March 2019.

APPENDIX A. AUTOMATION HIERARCHY AND WORKFLOW EXAMPLES

A.1 MOSAICS Workflow Hierarchy

MOSAICS leverages automation capabilities to perform a number of critical functions within the system. Automation is first used to model and baseline the ICS network, capturing the appropriate configuration and operational state of each component. The core MOSAICS components utilize this knowledge, along with available data from various sensors, logs, and auditing components, to recognize defined sets of behaviors that are indicative of potential threat activity. The automation capability then leverages integrations that make on-demand requests of these devices for additional enrichment information, as appropriate, based on the category of the alert. The alerts and corresponding data are made available to the ICS operators who can choose to address the related incidents with response actions. Once the appropriate actions are determined, the automation platform executes response actions chosen by the operator in an automated fashion, enabling more effective scale and speed in identifying and mitigating incidents within the ICS system.

The MOSAICS automation design implements a main, top-level workflow for each of the core functions of alert ingestion, detection, mitigation, recovery, and information sharing, as shown in Figure A-1. These main workflows have supporting sub-workflows that can be called to implement specific functionality.



SIEM: Security Information and Event Management; COA: Course of Action

Figure A-1 MOSAICS Hierarchy Design

Figure A-2 shows the next level of detail of the workflow design. This demonstrates how workflows are broken down to call supporting sub-workflows, which allows for easy extensibility as new alerts, mitigation, and response actions are added to the system.

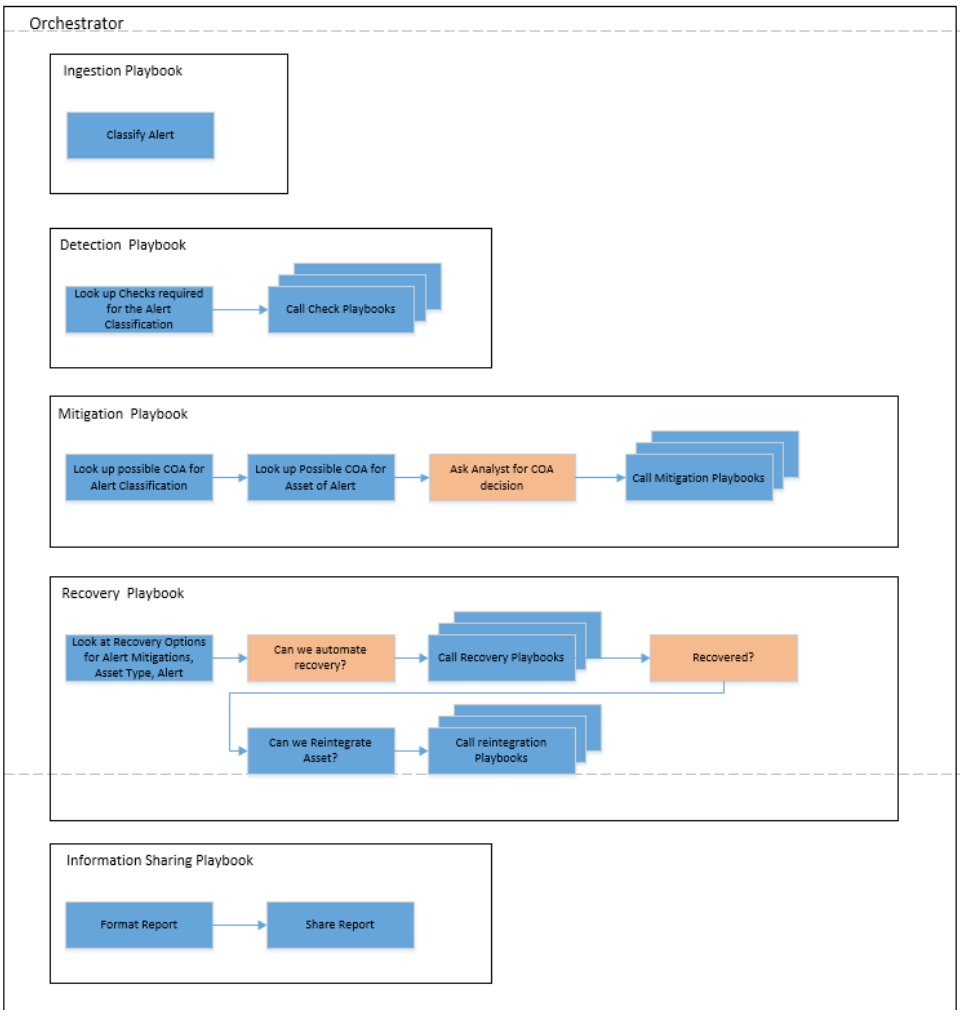


Figure A-2. MOSAICS Detailed View of Workflow Architecture

A.2 MOSAICS Workflow Execution

> ***Note:*** *While not all workflows described here are required for a MOSAICS Block 1 implementation, the full design is presented due to the interdependencies of the workflows and to ensure clarity of the automated processes.*

This section will utilize workflows developed for the MOSAICS Joint Capability Technology Demonstration (JCTD)[2], represented using Business Process Modeling Notation, to illustrate the execution of the MOSAICS workflow hierarchy. These workflows were originally developed using a commercial Security Orchestration, Automation and Response (SOAR) platform and are used simply as examples of how the automation in MOSAICS can be implemented, but are not

[2] MOSAICS Final Report

intended to be prescriptive. Workflows built for a MOSAICS implementation will need to be adjusted to accommodate differing control system environments and/or orchestration platforms.

A.3 Alert Processing Workflow Execution

The Main_Ingestion workflow (Figure A-3) is triggered by the SIEM flagging an event or series of events as suspicious and creating an alert. The alert tag designation is checked to determine what, if any, additional integrity checks are required to be executed against the associated control system assets. If no additional action is necessary, the alert is logged and workflow execution ends. However, if additional checks are required, the assets are placed in a maintenance mode and execution is passed to the detection workflow.

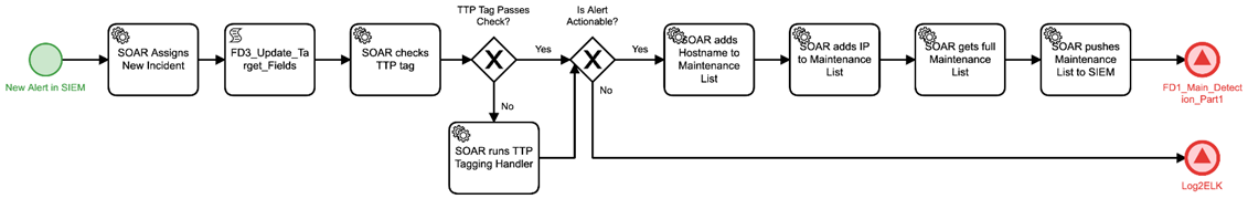
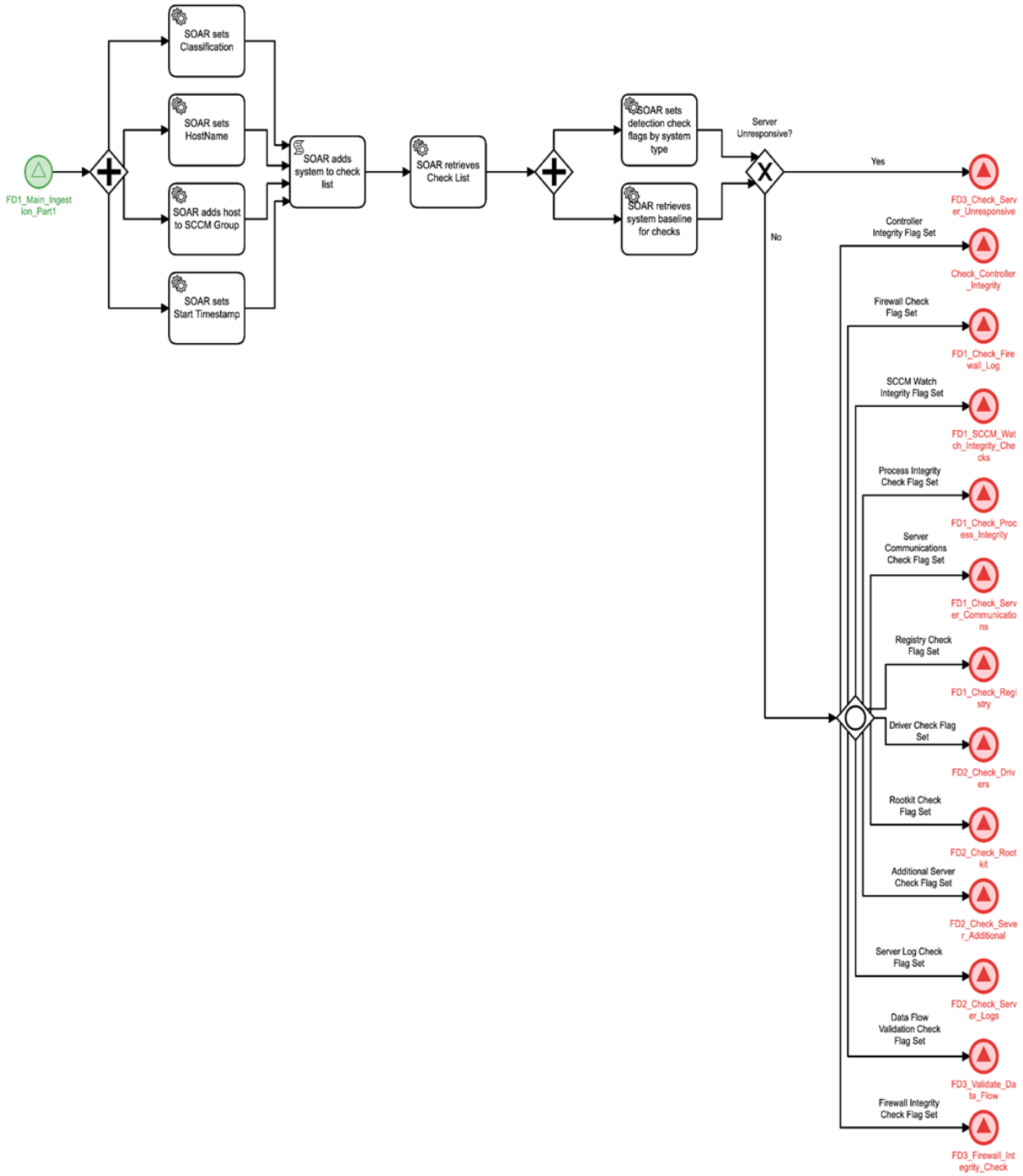


Figure A-3. FD1_Main_Ingestion_Part1

The Main_Detection workflow (Figure A-4) examines the classification of the alert and then obtains the list of associated Integrity Checks for that alert and asset type (e.g., Windows host, firewall, controller). Prior to executing any Integrity Checks, the workflow ensures that the asset is reachable and obtains all baseline information for the associated asset that will be used by the Integrity Checks. The detection workflow then executes the list of identified Integrity Checks in sequence to determine whether any additional anomalies or suspicious events exist.



SCCM: System Center Configuration Manager

Figure A-4. FD1_Main_Detection_Part1

Two representative samples of the Integrity Check workflows are shown in Figure A-5 and Figure A-6. In each case, the SOAR collects the most recent data from the asset (in these examples running processes and specific registry values) and compares that data to the baseline data

collected previously. Results of this comparison are captured and execution is returned to the Main_Detection workflow.

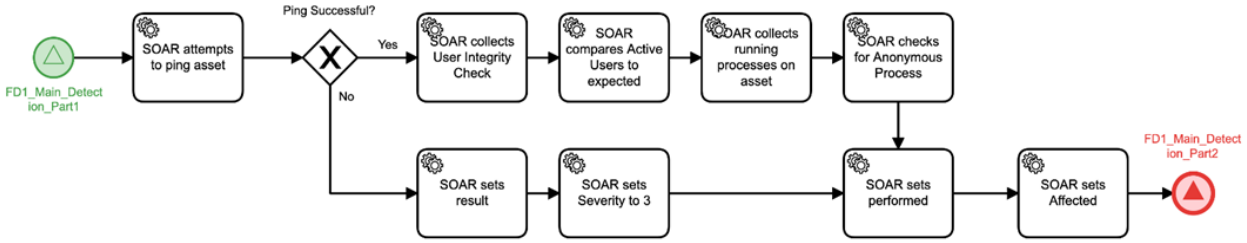


Figure A-5. FD1_Check_Process_Integrity

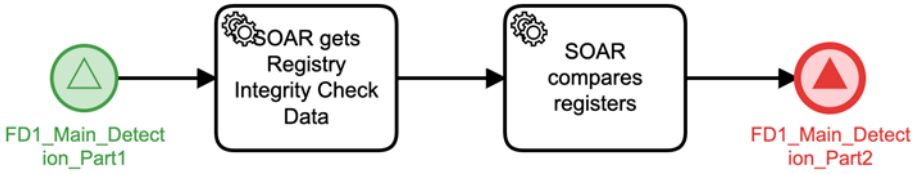
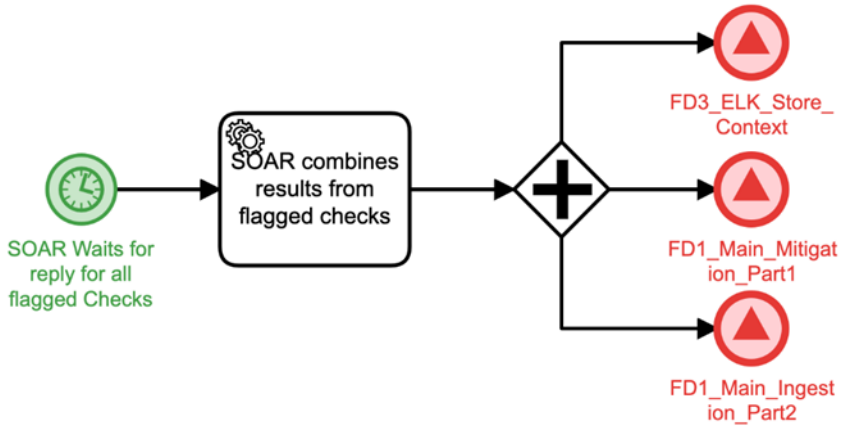


Figure A-6. FD1_Check_Registry

The Main_Detection workflow (Figure A-7) waits for completion of all Integrity Checks, and the results are logged back to the SIEM platform where it can be associated with the original alert. At this point, execution is passed back to the Main_Ingestion workflow, where the assets are removed from the maintenance list and the alert investigation is closed (Figure A-8).



ELK: Elastic Search, Logstash, and Kibana

Figure A-7. FD1_Main_Detection_Part2

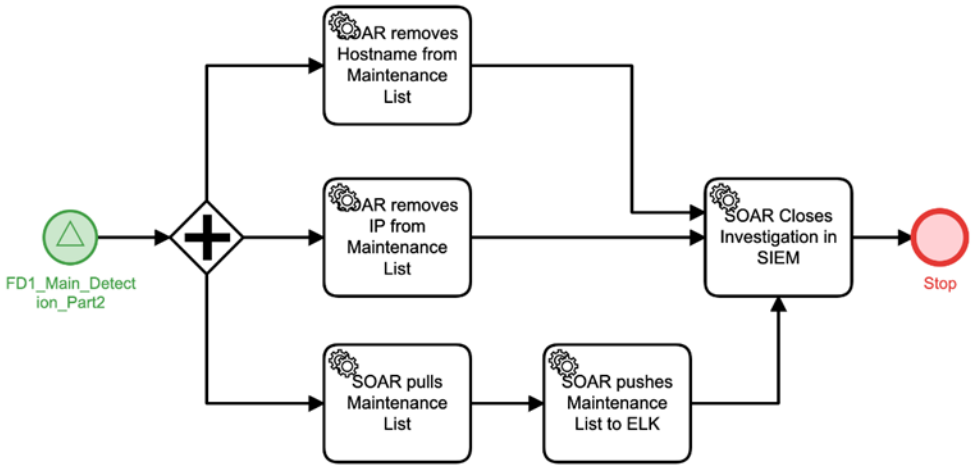


Figure A-8. FD1_Main_Ingestion_Part2

A.4 Mitigation Workflow Execution

In parallel to completing the alert investigation process outlined previously, the Main_Detection workflow also passes execution to the Main_Mitigation workflow (see Figure A-7). The Main_Mitigation workflow (Figure A-9) examines the severity of the alert and if it exceeds the set threshold, mitigation COAs are determined and all information related to the alert (e.g., correlated events, results of all Integrity Checks, COAs) is presented to the operator for "human-in-the-loop" decision-making.

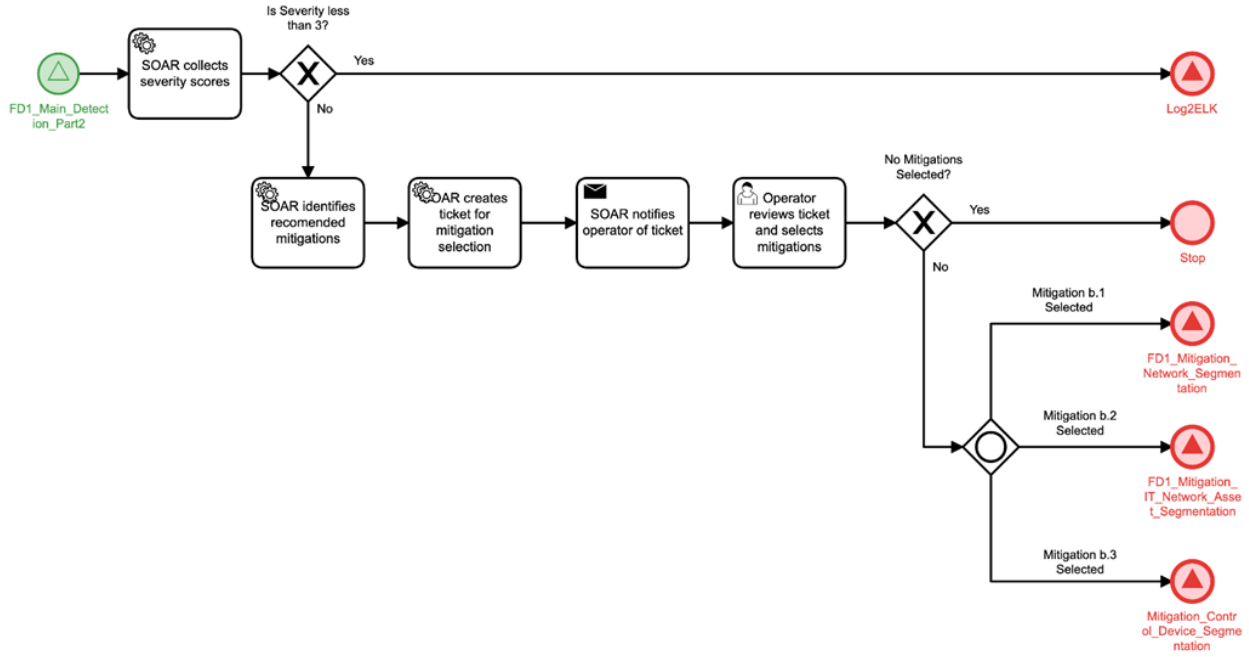


Figure A-9. FD1_Main_Mitigation_Part1

The operator can choose to take no action on the alert, in which case execution ends, or can select from the list of pre-approved COAs. When specific COAs are selected by the operator, execution is passed to the corresponding mitigation sub-workflow for automated implementation. Two

mitigation workflows were implemented as part of the MOSAICS JCTD. These COA sub-workflows focus on breaking adversarial command and control by implementing firewall rules that isolate the entire control system environment (Figure A-10) or a specific network asset (Figure A-11) from external communications.

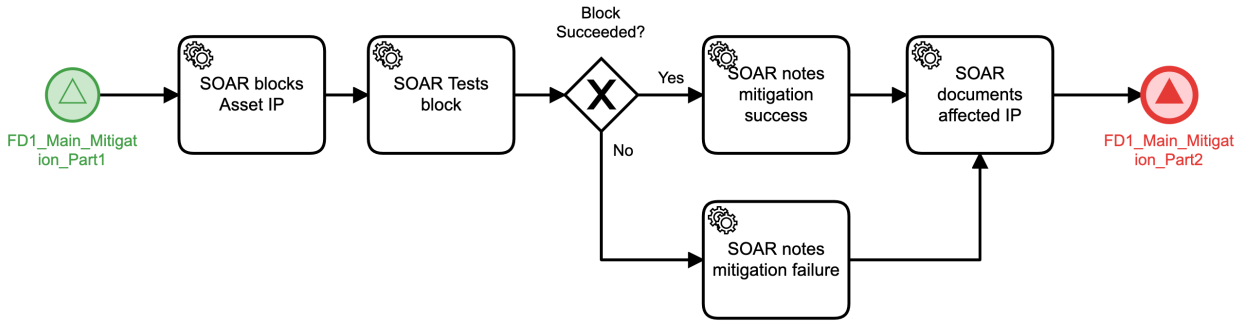


Figure A-10. FD1_Mitigation_Network_Segmentation

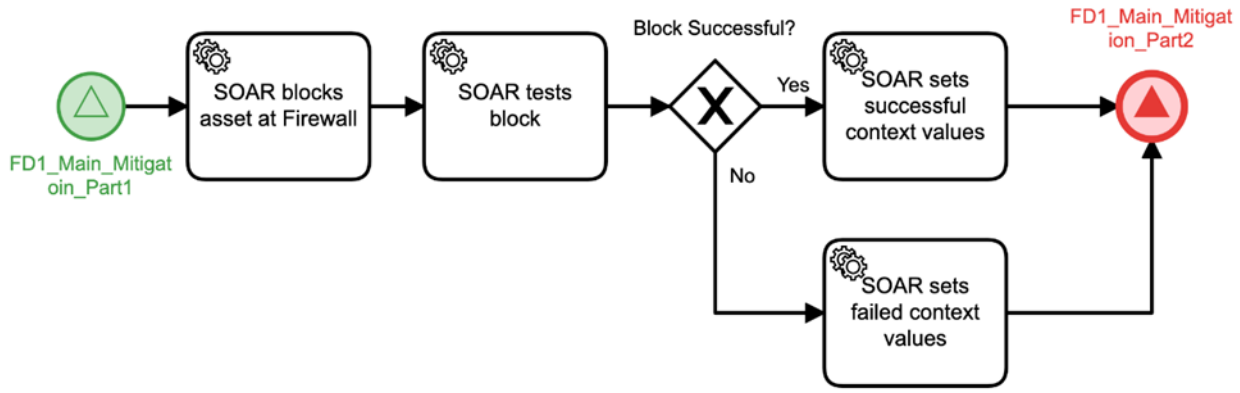


Figure A-11. FD1_Mitigation_IT_Network_Asset_Segmentation

Upon completion of the mitigation action, execution is returned to the Main_Mitigation workflow where all automated actions are logged, and the event is closed.

A.5 Information Sharing and Recovery Workflow Execution

Similar to the mitigation workflows, the Information Sharing and Recovery workflows are called based on operator-initiated actions to restore the system to a prior state and/or to share technical information related to an identified threat. The recovery workflow was not fully implemented as part of the MOSAICS JCTD effort, but a templated workflow was used to pass control to the Main_Information_Sharing workflow. This workflow (Figure A-12) collects all alert and Integrity Check data associated with an incident and formats it into a Structured Threat Information Exchange (STIX) bundle for machine-to-machine information sharing. At this point the event is closed, and no further action is taken on the alert.

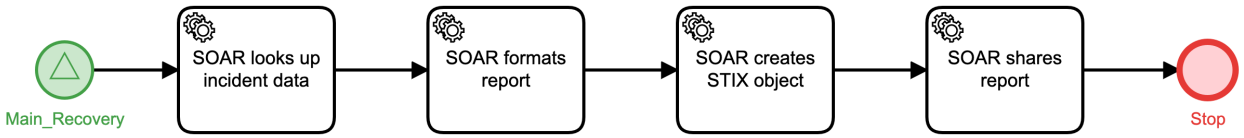


Figure A-12. Main_Information_Sharing

A.6 Full MOSAICS Workflow Representation

The complete end-to-end flow of all the MOSAICS workflows can be seen in Figure A-13. While this flow can be implemented in a variety of ways, this approach allows for easy extensibility as new alerts are developed, data sources are incorporated, pre-approved mitigations are defined, and response actions are added to the system.

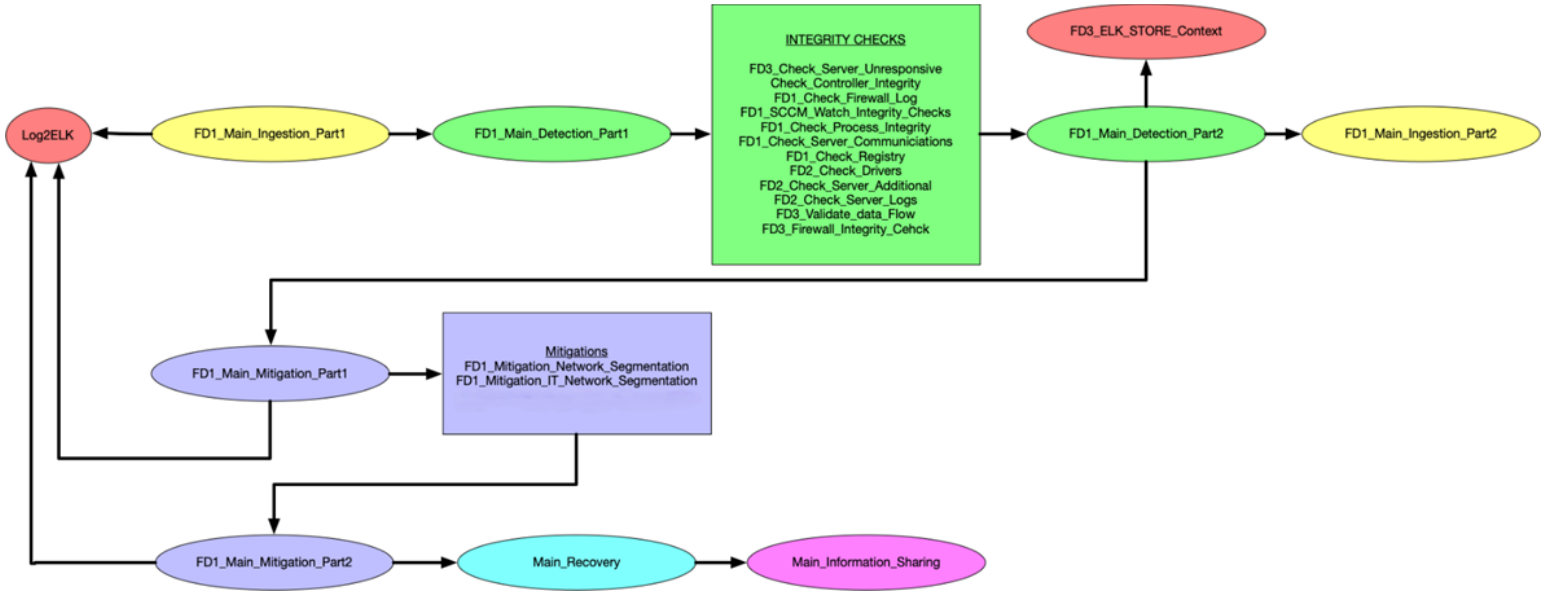


Figure A-13. MOSAICS Workflow Representation

APPENDIX B. BEHAVIORAL ALERTING SETS FOR CONTROL SYSTEMS (BAS/CS™)

BAS/CS™
Behavioral Alerting Sets for Control Systems

Behavioral Alerting Sets for Control Systems (BAS/CS™) is a JHU/APL alerting framework which implements the More Situational Awareness for Industrial Control Systems (MOSAICS) Block 1 alerting requirements. BAS/CS defines a data processing pipeline which firsts normalizes and tags events with BAS/CS Event IDs, then proceeds to correlate the events using BAS/CS Rules to produce alerts. Events are a captured change in the environment, and alerts are notifications of events that need operator attention. The tagging and correlation rules defined by BAS/CS is intended to be implemented in a commercial Security Information and Event Management (SIEM) capability or analytics platform.

B.1 BAS/CS™ Events

BAS/CS Events are defined as a list of events with standardized tags and names. BAS/CS Events provide broad behavioral groupings to categorize the types of events sensors may generate. This method of event tagging allows for flexibility in sensor capability selection. Vendor proprietary event analytics are mapped to a BAS/CS Event tag, standardizing how correlative analytics can be performed across diverse sensor event data. The BAS/CS Events were developed to meet the MOSAICS requirements detailed in Table B-1.

Table B-1. MOSAICS Requirements Satisfied by BAS/CS Events

ID	Requirement
F3.3.1	MOSAICS shall generate an event whenever any detection criteria (e.g., change in behavior, access/usage rule violation) not captured in the baseline is triggered
T3.3.3	MOSAICS shall categorize events with a normalized event tag Note: The tag is for use in analysis.
T3.3.4	MOSAICS events shall include the following, at a minimum: • All accompanying data elements used to generate the event • Timestamp of when event was created • Normalized event tag • Unique identifier

There are two main categories of BAS/CS Events (BE) as shown in Table B-2: Host and Network events. Host events focus on the events that would be generated from within a Host. Network events focus on events generated from network communications.

Table B-2. BAS/CS Events v1

BE ID	BE Name	BE Description
Host Events		
ACC01	Pass the Hash Attempt	NTLM or LM login attempt (a pass the hash (PtH) vulnerability)
ACC02	Remote Login Attempt	Authenticated remote login attempt (RDP, ssh, etc.)
ACC03	Successful Remote Login	Successful remote login (RDP, ssh, etc.)
ACC04	Admin Share Access	Modification of admin shares settings
ACC05	New Service	A new service was installed
ACC06	Scheduled Task	A scheduled task was created
ACC07	User Created	A new user account was created
ACC08	User Added to Security Global Group	A member was added to a security-enabled global group
ACC09	User Added to Security Local Group	A member was added to a security-enabled local group
ACC10	Local Group Change	A security-enabled local group was changed
ACC11	Explicit Login Attempt	New login attempt with explicit credentials
ACC12	Failed Login Attempt	Unsuccessful login attempt
ACC13	New Login	New logon session created
ACC14	File Share Write	Suspicious write or append to a common file share (SYSVOL or other)
LOG01	Significant Timestamp Difference	Significant timestamp difference in log
LOG02	Decrease in logging	Significant decrease in logging has been observed
FIL01	New File	A new file detected in a monitored file system
FIL02	File Deletion	A file was deleted from a monitored file system
PRO01	Process Change	A process has been created or changed
PRO02	Application Control Policy Block	Application control policies blocked an installer or script from executing (AppLocker or other)
PRO03	New Command/Scripting Interpreter or Exploitation	A new command/scripting interpreter or exploitation detected
PRO04	Suspicious Use of System Process	Suspicious use of a system process
PRO05	Process Stopped	A process was stopped
PRO06	Driver Loaded	New kernel driver loaded
PRO07	Potential Process Injection	Process injection potentially detected
PRO08	WMI Event Detected	A Windows Management Instrumentation (WMI) event filter or consumer activity has been detected
PRO09	Security Audit Logs Cleared	The security audit logs have been cleared
PRO10	System Logs Cleared	System logs have been cleared
PRO11	Event Logging Stopped	Event logging service has stopped

BE ID	BE Name	BE Description
PRO12	Outgoing Connection from Suspicious Process	Suspicious process connection detected
PRO13	Remote Management Executed Suspicious Process	Suspicious remote process execution was detected
PRO14	Remote Management Executed Suspicious Commands	Suspicious remote process command execution was detected
PRO15	Remote Service Management	Service control was used to create, modify, or start services on a remote host
PRO16	Named Pipe	A named pipe has been created or connected to
USB01	USB Peripheral Connected	A USB peripheral device has been connected
USB02	USB Peripheral Removed	A USB peripheral device has been removed
USB03	USB Storage Connected	A USB storage device has been connected
USB04	USB Storage Removed	A USB storage device has been removed
Network Events		
IDS01	Network Conversation Anomaly	A change in the normal conversations between nodes was observed
IDS02	New Node	A new network node has been established
IDS03	New Logical Link	A link (communication channel) has been established
IDS04	OT Write Command	A control system protocol write command was observed
IDS05	OT Read Command	A control system protocol read command was observed
IDS06	Function Code Anomaly	An unusual or new function code was observed
IDS07	Protocol Anomaly	Improper or unusual use of a network protocol was observed
IDS08	Configuration Change	A change to firmware, logic, or software program has occurred
IDS09	Hardware Change	Change to serial number, I/O hardware, etc.
IDS10	Network Interface Change	A change to a MAC or IP address has occurred
IDS11	External Conversation	A conversation with a node outside of control system network boundary has occurred
IDS12	Network Scanning	Asset or port scanning was observed
IDS13	System Elements Not Synchronized	A message with an anomalous time stamp was observed
IDS14	Device State Change	A mode change or reboot has occurred
IDS15	Signature Based Alerts	A signature-based alert has been generated
IDS16	Process Variable Anomaly	A process variable outside normal or expected ranges was observed
NET01	Link Traffic Increase	An unexpected increase in traffic has occurred
NET02	Link Traffic Decrease	An unexpected decrease in traffic has occurred
NET03	Link Loss	A communication link has dropped or been lost

BE ID	BE Name	BE Description
NET04	Stale Node	A node has stopped communicating
NET05	Network Scanning	Asset or port scanning has occurred
NET06	Network Interface Change	A change to a MAC or IP address has occurred

B.2 BAS/CS™ Alerts

BAS/CS Alerts are defined as a collection of correlations of BAS/CS Events. Each BAS/CS Rule consists of an Alert Logic statement, which provides the logical relationship between the BAS/CS Events using AND (&&) and OR (||) expressions. Each of these logical expressions are used to query the BAS/CS Event data in a SIEM, and if the logical expression returns True, for the given time range and aggregation field (typically the event source hostname), then an Alert is raised. The BAS/CS Alerts were developed to meet the MOSAICS requirements detailed in Table B-3 and a representative sample of the current list of BAS/CS Alerts is shown in Table B-4.

Table B-3. MOSAICS Requirements Satisfied by BAS/CS Alerts

ID	Requirement
F4.1.1	MOSAICS shall analyze events
T4.1.1.1	MOSAICS shall correlate events across assets, network communications, and time for analysis
T4.1.1.2	MOSAICS shall generate an alert based on predefined threat patterns of behavior

Table B-4. BAS/CS Alerts v1

Alert ID	Alert Name	Alert Description	Alert Logic
BAS.2.1	Unusual Account Activity	A new shell process has been created or AppLocker has warned against the execution of a script or installer (.msi) file. A user may be attempting to execute malicious commands, scripts, or binaries.	PRO02 || PRO03
BAS.3	Unusual Process Detected	A process has been detected that is not within the list of known, expected processes. An adversary may be executing malicious code on the system.	PRO01
BAS.5	Irregular Audit Log Event	One or more audit logs have been cleared or stopped, or contain significant timestamp differences. An attacker may be attempting to evade detection.	LOG01 || PRO09 || PRO10 || PRO11
BAS.7	Network Enumeration activity	A device is perceived to be communicating with other devices in an attempt to enumerate details about the endpoint devices.	IDS12 || NET05 || ((IDS02 || IDS03) && IDS05)

Alert ID	Alert Name	Alert Description	Alert Logic
BAS.8.1	Unexpected OT Command Activity	Unexpected behavior of an HMI, OPC, or control server affecting control equipment. HMI or OPC not updating after operator made changes to instructions, commands, or alarm thresholds. Expected changes are not appearing on control equipment.	(IDS04 || IDS06 || IDS07) && (NET03 || IDS13 || IDS14 || IDS16)

B.3 Implementing BAS/CS™

In order to implement BAS/CS, the additional detection functional requirements listed in Table B-5 and all the supporting technical requirements must be satisfied by the deployed sensor capabilities and SIEM infrastructure. These requirements define what events need to be detected, and lay the foundation for having event data which may be tagged with BAS/CS Event IDs.

Table B-5. MOSAICS Requirements BAS/CS Events expects to be satisfied by sensor capabilities

ID	Requirement
F3.1.1	MOSAICS shall continuously monitor network communication within the protected enclave
F3.1.2	MOSAICS shall continuously monitor the status of protected enclave assets
F3.2.1	MOSAICS shall detect changes to the configuration of protected enclave assets
F3.2.2	MOSAICS shall detect abnormal behavior of protected enclave assets
F3.2.3	MOSAICS shall detect malicious indicators on protected enclave assets
F3.2.4	MOSAICS shall detect changes to the configuration of protected enclave network communications
F3.3.5	MOSAICS shall detect abnormal behavior of the protected enclave network communications
F3.3.6	MOSAICS shall detect malicious indicators on the protected enclave network communications

The Tagging of the BAS/CS Events can occur as a part of several capabilities. First, the endpoint sensors could implement the BAS/CS Event tagging, so all events generated would have the BAS/CS Event ID (BE ID) as an event field. If the sensor does not implement the tagging, then an event aggregation capability could implement the tagging with a lookup table pipeline. This pipeline would inspect each event received, compare the event details to a lookup table and add a new BE ID field with the proper BE ID tagged. Lastly, if no event aggregator is in use, the SIEM could have a pre-indexing processor to implement the same method as the event aggregator, but within the SIEM.

BAS/CS Rules are implemented within the SIEM or analytics platform with access to the common event database. The BAS/CS Rules are defined in JSON, available by request from JHU/APL, allowing them to be converted into the custom formats each SIEM needs to ingest and implement

the rule. BAS/CS Rules require all the MOSAICS Event requirements to be met, in addition to the following event generation requirements in Table B-6.

Table B-6. MOSAICS Requirements BAS/CS Events expects to be previously satisfied

ID	Requirement
T3.3.1	MOSAICS shall store events in a common data repository
T3.3.2	MOSAICS shall generate an event within 1 minute of the activity resulting in the event

Figure B-1 shows an example of how the BAS/CS Rule JSON can be implemented in Elasticsearch. This implementation was accomplished with a custom script which read the BAS/CS Rule JSON file, renamed the Fields, and converted the logic into the syntax expected by Elasticsearch. The script then exported the new rule as a ndjson file, which is the file type Elasticsearch expects for rule imports. This file can then be manually imported into the Elasticsearch instance, or loaded with API calls.

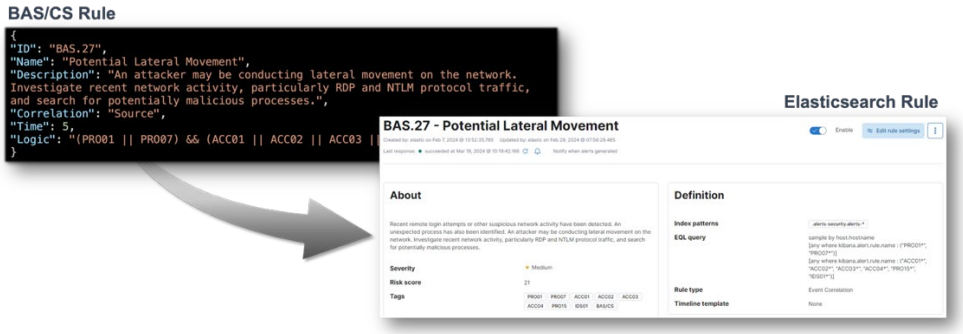


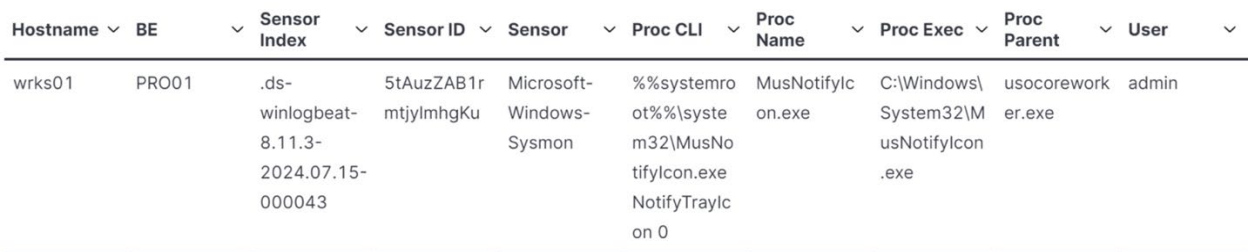
Figure B-1. BAS/CS Rule Converted to an Elastic Security Rule

APPENDIX C. OPERATOR VISUALIZATION EXAMPLES

This Appendix contains example screenshots for the implementation of MOSAICS visualization requirements. These are examples only and do not prescribe this particular implementation.
The first example, Figure C-1, is an event visualization in table form. The columns include the Behavioral Alert Set for Control Systems (BAS/CS™) event identifier (see Appendix B) (BE column), the sensor that detected the event (Sensor Index and Sensor ID columns), additional information about the process that triggered the event (Proc CLI, Name, Exec, and Parent columns), and information about the user (User column). Each of the columns are both filterable and sortable (ascending/descending). This visualization is an example related to requirements in Table C-1.

Table C-1. MOSAICS Event Visualization Requirements Example

ID	Requirement
F5.1.1	MOSAICS shall provide the capability to visualize detected events.
T5.1.1.2	MOSAICS shall allow a user to perform sorts on event data.
T5.1.1.3	MOSAICS shall allow a user to perform filtering on event data.
F5.2.1	MOSAICS shall provide the capability to visualize the protected enclave status
T5.2.1.1	MOSAICS shall allow the user to view logs, events and alerts.



Hostname	BE	Sensor Index	Sensor ID	Sensor	Proc CLI	Proc Name	Proc Exec	Proc Parent	User
wrks01	PRO01	.ds-winlogbeat-8.11.3-2024.07.15-000043	5tAuzZAB1rmtjyImhgKu	Microsoft-Windows-Sysmon	%%systemroot%%\system32\MusNotifyIcon.exe NotifyTrayIcon 0	MusNotifyIcon.exe	C:\Windows\System32\MusNotifyIcon.exe	usocoreworker.exe	admin

Figure C-1. MOSAICS Event Visualization in a Table Format

Figure C-2 is an example showing how the alerts are displayed in table format. Each alert is given a unique identifier (Alert ID), the timestamp at which the alert was created, the affected host(s), a description of the alert, a description of the events that caused the alert (BE Summary), and a severity level. Each of the columns in the Figure C-2 screenshot are both filterable and sortable for investigative purposes. This visualization is an example that pertains to the requirements in Table C-2.

Table C-2. Alert Table Visualization Requirements

ID	Requirement
F5.2.1	MOSAICS shall provide the capability to visualize the protected enclave status
T5.2.1.1	MOSAICS shall allow the user to view logs, events and alerts.
F5.3.2	MOSAICS shall provide the capability to visualize alerts.

ID	Requirement
T5.3.2.1	MOSAICS shall have the capability to visualize any alert
T5.3.2.2	MOSAICS shall have the capability to see correlated events for a given alert.
T5.3.2.4	MOSAICS shall provide the ability to search, sort, and filter alerts by data attributes.

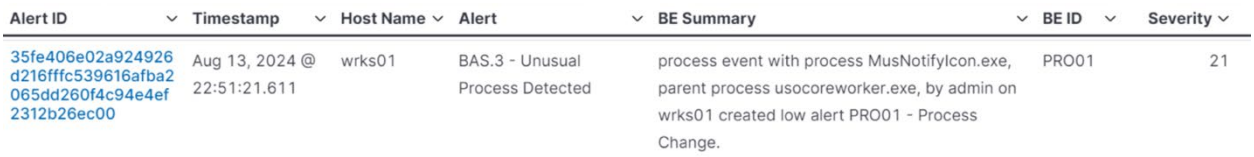


Figure C-2. MOSAICS Alert Table Visualization

The example shown in Figure C-3 highlights how an alert can be a result of multiple events. Here, an alert was a result of event IDs ACC06 and FIL01, since the events that occurred were a new scheduled task and a new file created. The combination of these events became an alert for a potential malicious persistence being established.

Figure C-3. MOSAICS Alerts as a Result of Multiple Events

The example in Figure C-4 shows a breakdown by workstation and alerts for the protected enclave. The operator is able to digest what issues are plaguing which assets in an easily identifiable manner. In addition, there is a sorted table on the right of the visualization that provides the totals for each type of alert across all assets as a way to understand the impacts to the enclave. This visualization is an example related to the requirements in Table C-3.

Table C-3. MOSAICS Incident Breakdown Requirements

ID	Requirement
F5.2.1	MOSAICS shall provide the capability to visualize the protected enclave status
T5.2.1.1	MOSAICS shall allow the user to view logs, events and alerts.
T5.2.1.2	MOSAICS shall provide the capability to display which asset of the protected enclave have been affected by alerts and events
F5.3.2	MOSAICS shall provide the capability to visualize alerts.
T5.3.2.7	MOSAICS shall perform trending and charting of alert/incident data.

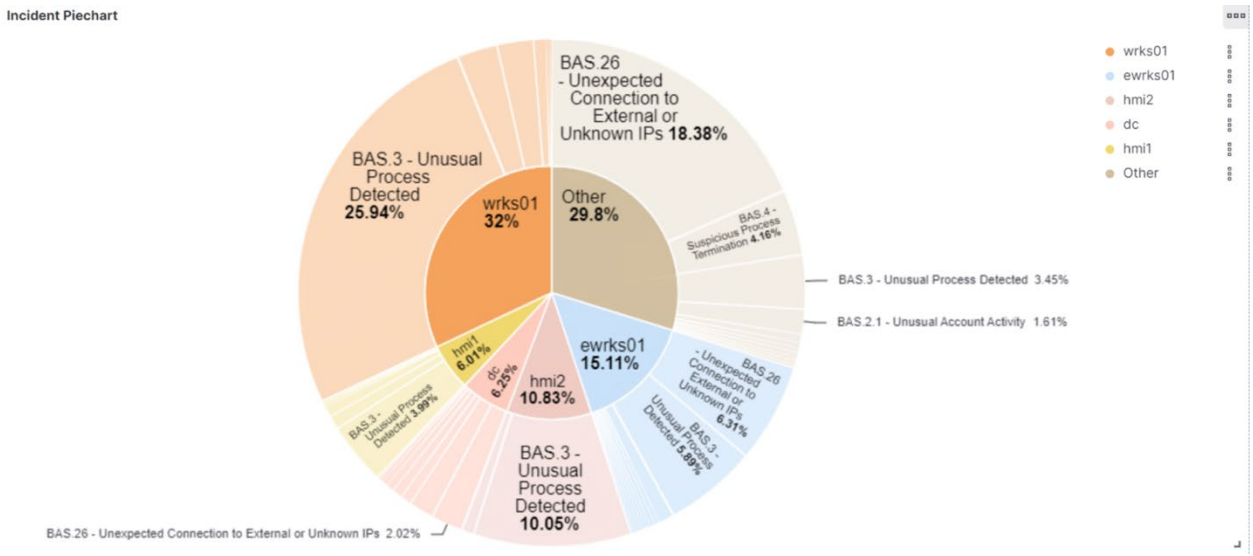


Figure C-4. MOSAICS Incident Breakdown Visualization

MOSAICS has the capability to aggregate each host for the processes and the users that have logged onto the machine. In addition, MOSAICS has the capability to keep track of which user is logged into an asset, so when an alert occurs, it can be correlated for where the potential security issues may be coming from. This visualization (Figure C-5) is an example for a single asset and is related to the requirements in Table C-4.

Table C-4. MOSAICS Asset User Table Requirement

ID	Requirement
F5.2.1	MOSAICS shall provide the capability to visualize the protected enclave status
T5.2.1.4	MOSAICS shall provide the capability to display the user accounts logged in to assets monitored by MOSAICS.

Top 50 values of user.name	Unique count of kibana.alert.reason
admin	1,105
SYSTEM	316
oozwald	154
LOCAL SERVICE	124
wtpadmin	114
EWRKS01$	14
NETWORK SERVICE	8
DWM-11	3
DWM-9	3

Figure C-5. MOSAICS Asset User Account Table

MOSAICS is able to search alerts to assist the operator examining alerts. In the example shown in Figure C-6, MOSAICS is able to search using wildcards in order to find specific strings in the Summary field of the Alert table. For each example alert noted, the phrase "Logical Link" can be found. In this example, MOSAICS has the capability to either search for the entire matching text or just a specific phrase the operator is interested in. This search, and the table, is an example related to the requirements in Table C-5.

Table C-5. MOSAICS Searching Capability Requirement

ID	Requirement
F5.3.2	MOSAICS shall provide the capability to visualize alerts.
T5.3.2.4	MOSAICS shall provide the ability to search, sort, and filter alerts by data attributes.

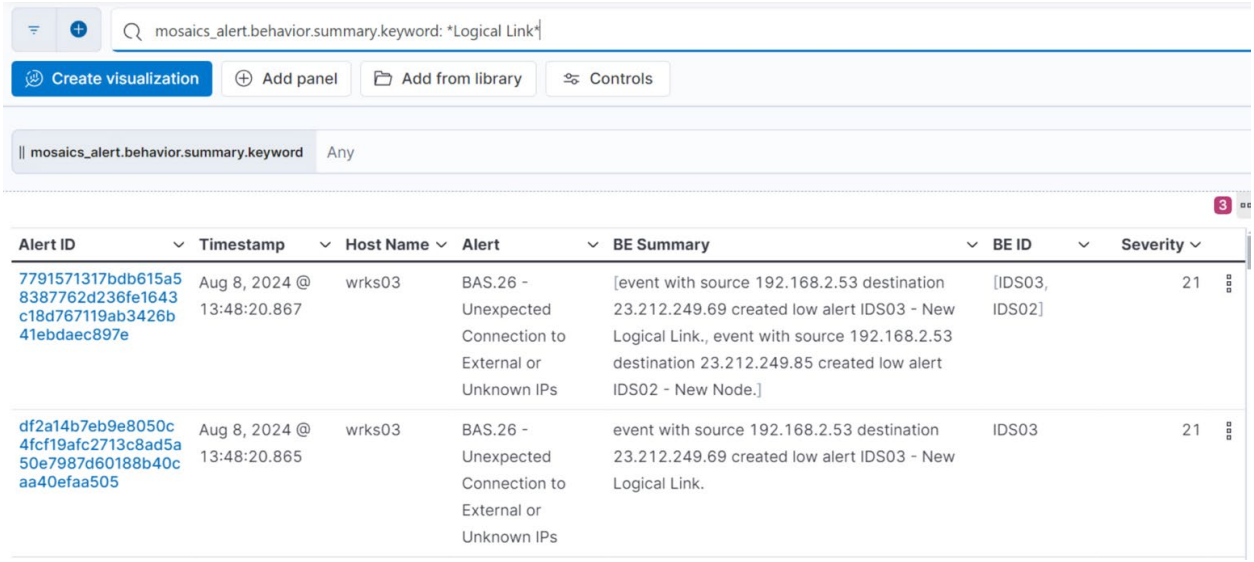


Figure C-6. MOSAICS Searching Capability

APPENDIX D. ACRONYMS

ACI TTP	Cyber Industrial Control System Tactics, Techniques, and Procedures
ADS	Alternate Data Streams
AI	Artificial Intelligence
API	Application Programming Interfaces
ARP	Address Resolution Protocol
BAS/CS™	Behavioral Alert Set for Control Systems
BE	BAS/CS™ Event
COA	Course of Action
COTS	Commercial off the Shelf
DCS	Distributed Control Systems
DHCP	Dynamic Host Configuration Protocol
DoD	Department of Defense
ELK	Elastic Search, Logstash, and Kibana
FTP	File Transfer Protocol
GOTS	Government off the Shelf
IACD	Integrated Adaptive Cyber Defense
ICS	Industrial Control System
ID	Identifier
IDS	Intrusion Detection System
IP	Internet Protocol
ISA	Interconnection Security Agreement
IT	Information Technology
JCTD	Joint Capability Technology Demonstration
JHU/APL	The Johns Hopkins University Applied Physics Laboratory
LMHOSTS	LAN Manager Hosts
MAC Address	Media Access Control Address
ML	Machine Learning
MOSAICS	More Situational Awareness for Industrial Control Systems
OS	Operating System
OT	Operational Technology
PLC	Programmable Logic Controller
RBAC	Role Based Access Control
RDP	Remote Desktop Protocol
SCADA	Supervisory Control and Data Acquisition
SCCM	System Center Configuration Manager
SIEM	Security Information and Event Management
SOAR	Security Orchestration and Automated Response
SPAN	Switched Port Analyzer
SSH	Secure Shell
STIX	Structured Threat Information Exchange
TTP	Tactics, Techniques, and Procedures
USB	Universal Serial Bus
WMI	Windows Management Instrumentation