

**NISTIR 8219**

# **Securing Manufacturing Industrial Control Systems: Behavioral Anomaly Detection**

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1    **Abstract**

2    Industrial control systems (ICS) are used in many industries to monitor and control physical  
3    processes. As ICS continue to adopt commercially available information technology (IT) to  
4    promote corporate business systems' connectivity and remote access capabilities, ICS  
5    become more vulnerable to cybersecurity threats. The National Institute of Standards and  
6    Technology's (NIST's) National Cybersecurity Center of Excellence (NCCoE), in  
7    conjunction with NIST's Engineering Laboratory (EL), has demonstrated a set of behavioral  
8    anomaly detection (BAD) capabilities to support cybersecurity in manufacturing  
9    organizations. The use of these capabilities enables manufacturers to detect anomalous  
10   conditions in their operating environments to mitigate malware attacks and other threats to  
11   the integrity of critical operational data. NIST's NCCoE and EL have mapped these  
12   demonstrated capabilities to the Cybersecurity Framework and have documented how this set  
13   of standards-based controls can support many of the security requirements of manufacturers.  
14   This report documents the use of BAD capabilities in two distinct, but related, demonstration  
15   environments: a robotics-based manufacturing system and a process control system that  
16   resembles what is being used by chemical manufacturing industries.

17   **Audience**

18   This report is intended for individuals or entities that are interested in understanding BAD  
19   technologies and their application to ICS environments. Additionally, this report is intended  
20   for those who are interested in understanding how to implement BAD tools in ICS and other  
21   operational technology environments.

22   **Keywords**

23   *BAD; behavioral anomaly detection; cybersecurity; Cybersecurity Framework; ICS;  
24   industrial control systems; manufacturing; process control*

25   **Acknowledgments**

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30

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31    **Executive Summary**

32    NIST's NCCoE, with NIST's EL and NCCoE collaborators, offers information regarding the  
33    use of BAD capabilities to support cybersecurity in ICS for manufacturing. This National  
34    Institute of Standards and Technology Interagency Report (NISTIR) was developed in  
35    response to feedback from members of the manufacturing sector concerning the need for  
36    cybersecurity guidance.

37    Cybersecurity attacks directed at manufacturing infrastructure can be detrimental to both  
38    human life and property. BAD mechanisms support a multifaceted approach to detecting  
39    cybersecurity attacks against ICS devices on which manufacturing processes depend, in order  
40    to permit the mitigation of those attacks.

41    The NCCoE and EL deployed commercially available hardware and software provided by  
42    industry, in response to a NIST notice in the Federal Register, in order to demonstrate BAD  
43    capabilities in an established laboratory infrastructure. We mapped security characteristics of  
44    the demonstrated capabilities to the *Framework for Improving Critical Infrastructure*  
45    *Cybersecurity* [1] based on NISTIR 8183, the *Cybersecurity Framework Manufacturing*  
46    *Profile* [2]. The mapping can be used as a reference in applying specific security controls  
47    found in prominent industry standards and guidance.

48    Introducing anomalous data into a manufacturing process can disrupt operations, whether  
49    deliberately or inadvertently. The goal of this NISTIR is to provide practical approaches for  
50    manufacturers to use in their efforts to strengthen the cybersecurity of their manufacturing  
51    processes. This NISTIR demonstrates how BAD tools can be used as a key security  
52    component in sustaining business operations, particularly those based on ICS. The examples  
53    provided in this NISTIR illustrate how detecting anomalous conditions can improve the  
54    reliability of ICS, in addition to providing specific cybersecurity benefits.

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211    **1. Introduction**

212    The goal of this National Institute of Standards and Technology Interagency Report  
213    (NISTIR) is to show practical approaches that manufacturers can use to strengthen  
214    cybersecurity in their manufacturing processes. Behavioral anomaly detection (BAD) tools  
215    can provide a key security component for sustaining business operations, particularly those  
216    based on industrial control systems (ICS). Because introducing anomalous data into a  
217    manufacturing process can disrupt operations, whether deliberately or inadvertently, the  
218    examples provided in this NISTIR demonstrate how detecting anomalous conditions can  
219    improve the reliability of manufacturing and other ICS, in addition to providing the  
220    demonstrated cybersecurity benefits.

221    **1.1. Background**

222    As stated in the National Institute of Standards and Technology (NIST) Special Publication  
223    (SP) 800-82 [3], ICS are vital to the operation of the United States' critical infrastructures,  
224    which are often highly interconnected and mutually dependent systems. While federal  
225    agencies also operate many ICS, approximately 90 percent of the nation's critical  
226    infrastructures are privately owned and operated. As ICS increasingly adopt information  
227    technology (IT) to promote corporate business systems' connectivity and remote access  
228    capabilities by using industry-standard computers, operating systems (OSs), and network  
229    protocols, the accompanying integration provides significantly less isolation for ICS from the  
230    outside world. While security controls have been designed to deal with security issues in  
231    typical IT systems, special precautions must be taken when introducing these same  
232    approaches in ICS environments. In some cases, new security techniques tailored to the  
233    specific ICS environment are needed. NIST recognizes this concern and is working with  
234    industry to solve these challenges through the development of reference designs and the  
235    practical application of cybersecurity technologies. BAD is one tool for improving ICS  
236    security.

237    NIST's National Cybersecurity Center of Excellence (NCCoE), in conjunction with NIST's  
238    Engineering Lab (EL) and NCCoE industry collaborators, has demonstrated a set of BAD  
239    capabilities to support cybersecurity in manufacturing organizations. The use of these  
240    capabilities enables manufacturers to detect anomalous conditions in their operating  
241    environments to mitigate malware attacks and other threats to the integrity of critical  
242    operational data. NIST's NCCoE and EL have mapped these demonstrated capabilities to the  
243    NIST Cybersecurity Framework [1] and have documented how this set of standards-based  
244    controls can support many of the security requirements of manufacturers. This NISTIR  
245    documents the use of BAD capabilities in two distinct, but related, demonstration  
246    environments: a collaborative robotics-based manufacturing system and a process control  
247    system (PCS) that resembles what is being used by chemical manufacturing industries.

248    **1.2. Purpose and Scope**

249    The scope of this NISTIR is a single cybersecurity capability. The security characteristics of  
250    different BAD approaches were mapped to the Cybersecurity Framework. The mapping  
251    points manufacturers to specific security controls found in prominent cybersecurity  
252    standards.

253    **1.3. Challenges**

254    Cybersecurity is essential to the safe and reliable operation of modern industrial processes.  
255    Threats to ICS can come from numerous sources, including hostile governments, criminal  
256    groups, disgruntled employees, other malicious individuals, unanticipated consequences of  
257    component interactions, accidents, and natural disasters. The Cybersecurity Framework [1]  
258    addresses identifying threats and potential vulnerabilities; preventing and detecting events;  
259    and responding to, and recovering from, incidents. It is not possible to prevent all cyber  
260    events. It may not even be possible to identify all threats for which ICS need to be prepared.  
261    It is certainly necessary to detect incidents before the response to, or recovery from, the  
262    incidents can be undertaken. Therefore, the detection of cyber incidents is an essential  
263    element for cybersecurity.

264    Many incident-detection tools involve monitoring system behaviors for out-of-specification  
265    settings or readings or for predefined threat signatures (information elements previously  
266    identified as being associated with threats or vulnerability characteristics). However, as  
267    previously mentioned, not all threats and vulnerabilities are known beforehand (e.g., zero-  
268    day attacks); therefore, not all threats and vulnerabilities can be included among signatures  
269    for which monitoring is undertaken. BAD involves the continuous monitoring of systems for  
270    unusual events or trends. The monitor looks for evidence of compromise, rather than for the  
271    attack itself.

272    The challenge addressed by this project is to demonstrate example implementations of BAD  
273    capabilities that manufacturers can adopt to achieve their cybersecurity goals. Specifically,  
274    this project responds to a need within the manufacturing community to improve the ability to  
275    detect anomalous behavior in real or near-real time. Early detection of potential cybersecurity  
276    incidents is key to helping reduce the impact of these incidents for ICS.

277    **1.4. Approach to Addressing Challenges**

278    The NCCoE developed and demonstrated a set of example approaches for detecting  
279    anomalous conditions within manufacturers' ICS environments. These examples include  
280    recommendations that are practical for businesses to implement to strengthen cybersecurity  
281    in their manufacturing processes, with an additional potential for detecting anomalous  
282    conditions not related to security, such as equipment malfunctioning.

283    The NCCoE examples provide the following capabilities:

- 284       • models of BAD capabilities that manufacturers can adopt to achieve their security  
285       goals for mitigating the risks posed by threats to cybersecurity  
286       • nonintrusive techniques to analyze industrial network communications, allowing the  
287       existing ICS infrastructure to flow through the network without interruption or a  
288       performance impact  
289       • establishment of one or more baselines, and notification when specific changes or  
290       anomalies occur in the environment over time  
291       • identification of new devices on the ICS network and of assets that have disappeared  
292       from the network

- 293       • detection of unauthorized configuration changes and of the transfer of files in the  
294            network  
295       • increased visibility into network operation and real-time alerting

296 The NCCoE used commercially available products provided by industry collaborators to  
297 address this cybersecurity challenge. These products were provided under Cooperative  
298 Research and Development Agreements. This NISTIR does not endorse any products and  
299 does not guarantee compliance with any regulatory initiatives. An organization's information  
300 security experts should identify the products that will best integrate with their existing tools,  
301 processes, and system infrastructure. Organizations can adopt one of the demonstrated  
302 approaches or another one that adheres to the suggested guidelines. This NISTIR can also be  
303 used as a starting point for implementing BAD.

304 **1.5. Benefits**

305 This NISTIR is intended to help organizations accomplish their goals by using anomaly  
306 detection tools for the following purposes:

- 307       • detect cyber incidents in time to permit effective response and recovery  
308       • expand visibility and monitoring capabilities within manufacturing control systems,  
309            networks, and devices  
310       • reduce opportunities for disruptive cyber incidents by providing real-time monitoring  
311            and anomaly-detection alerts  
312       • support the oversight of resources (e.g., IT, personnel, data)  
313       • enable faster incident-response times, fewer incidents, and shorter downtimes

314 **2. Cybersecurity Framework and NIST Manufacturing Profile**

315 The *Framework for Improving Critical Infrastructure Cybersecurity* [1] is a voluntary  
316 risk-based assemblage of industry standards and best practices designed to help organizations  
317 manage cybersecurity risks. The Cybersecurity Framework, created through collaboration  
318 between government and the private sector, uses a common language to address and manage  
319 cybersecurity risk in a cost-effective way, based on business needs, without imposing  
320 additional regulatory requirements. The *Cybersecurity Framework Manufacturing Profile* [2]  
321 defines specific cybersecurity activities and outcomes for the protection of the manufacturing  
322 system and its components, facility, and environment. By using the profile, the manufacturer  
323 can align cybersecurity activities with business requirements, risk tolerances, and resources.  
324 The profile provides a manufacturing sector-specific approach to cybersecurity from  
325 standards, guidelines, and industry best practices.

326 Table 2-1 maps functions addressed by BAD capabilities to NIST Cybersecurity Framework  
327 functions as presented in the profile. In Table 2-1, the references to the requirements are  
328 American National Standards Institute / International Society of Automation Standard 62443-  
329 2-1 (*Security for Industrial Automation and Control Systems: Establishing an Industrial*  
330 *Automation and Control Systems Security Program*) [4], American National Standards  
331 Institute / International Society of Automation Standard 62443-2-3 (*Security for Industrial*  
332 *Automation and Control Systems – Part 2-3: Patch Management in the IACS Environment*)

333 [5], and NIST SP 800-53 (*Security and Privacy Controls for Federal Information Systems*  
334 *and Organizations*) [6].

**Table 2-1 Mapping of Cybersecurity Framework Functions Addressed by BAD Capabilities to the Manufacturing Profile**

Function	Category	Subcategory	Manufacturing Profile	Reference
Detect	Anomalies and Events (DE.AE)	DE.AE-2	<b>Low</b>	62443-2-1:2009 4.3.4.5.6, 62443-2-3:2015 SR 2.8, 2.9
			Review and analyze detected events within the manufacturing system to understand attack targets and methods	<a href="#">AU-6</a> <a href="#">IR-4</a>
			<b>Moderate and High</b>	<a href="#">AU-6(1)</a> <a href="#">IR-4(1)</a>
		DE.AE-3	Employ automated mechanisms, where feasible, to review and analyze detected events within the manufacturing system	<a href="#">AU-6(1)</a> <a href="#">IR-4(1)</a>
			<b>Low and Moderate</b>	62443-3-3:2013 SR 6.1
			Ensure that event data is compiled and correlated across the manufacturing system by using various sources, such as event reports, audit monitoring, network monitoring, physical access monitoring, and user/administrator reports	<a href="#">IR-5</a>
		DE.AE-4	<b>High</b>	
			Integrate the analysis of events, where feasible, with the analysis of vulnerability scanning information, performance data, manufacturing system monitoring, and facility monitoring to further enhance the ability to identify inappropriate or unusual activity	<a href="#">AU-6(5)(6)</a> <a href="#">AU-12(1)</a>
			<b>Low</b>	
			Determine the negative impacts, resulting from detected events, to manufacturing operations, assets, and individuals, and correlate the impacts with the risk assessment outcomes	<a href="#">RA-3</a>
			<b>Moderate</b>	
			Employ automated mechanisms to support impact analysis	<a href="#">IR-4(1)</a> <a href="#">SI-4(2)</a>
			<b>High</b>	
			Correlate detected event information and responses to achieve perspective on the event's impact across the organization	<a href="#">IR-4(4)</a>

338    **3. Demonstration Environment Architecture**

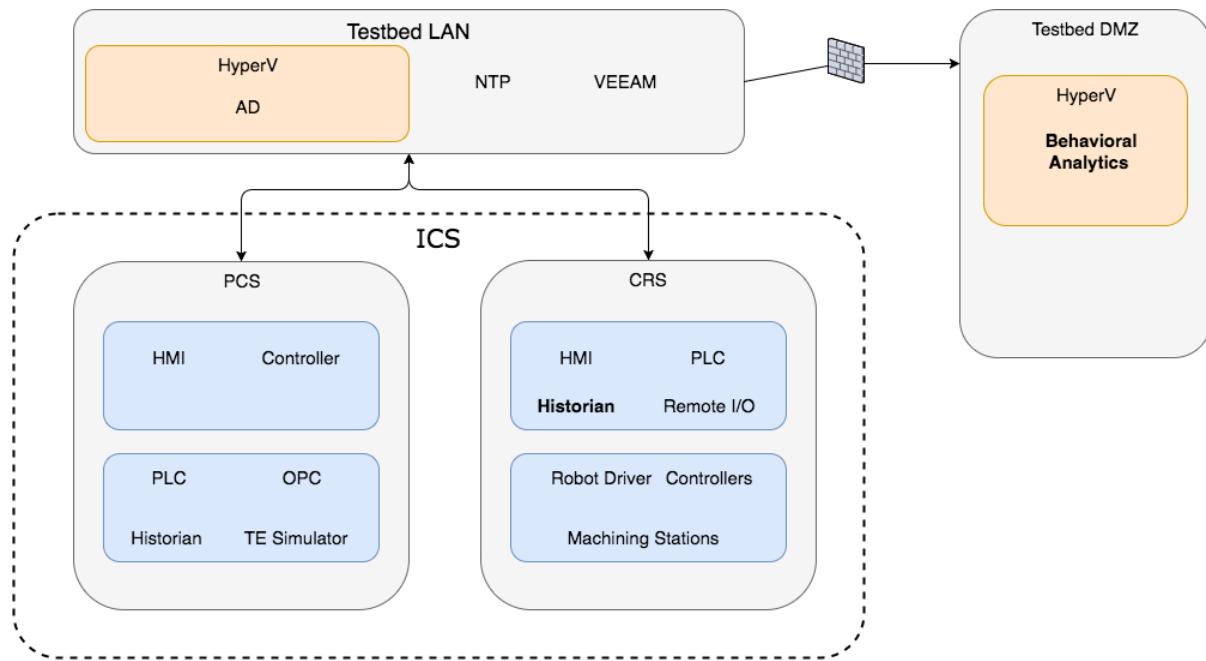
339    The Cybersecurity for Smart Manufacturing Systems (CSMS) demonstration environment  
340    emulates real-world manufacturing processes and their ICS by using software simulators and  
341    commercial off-the-shelf hardware in a laboratory environment [7]. The CSMS environment  
342    was designed to measure the performance impact on ICS that is induced by cybersecurity  
343    technologies. The PCS and the collaborative robotic system (CRS) are the two systems used  
344    for the demonstration of BAD capabilities. The PCS and CRS demonstration enclaves are  
345    described in Sections 3.1 and 3.2.

346    Figure 3-1 depicts a high-level architecture for the BAD demonstration environment. The  
347    capabilities that are introduced in the demonstration environment are bolded in Figure 3-1  
348    and address the Cybersecurity Framework functions and subcategories listed in Table 2-1.

349    The local area network (LAN), a firewalled-off cybersecurity tool environment  
350    (demilitarized zone [DMZ]), and two ICS environments make up the existing architecture of  
351    the CSMS demonstration environment. The LAN consists of a hypervisor for virtualization, a  
352    network time protocol (NTP) server for time synchronization, a server for backup and  
353    storage, and a virtualized Active Directory server for domain services. Within the  
354    demonstration environment's DMZ, there is a hypervisor that allows cybersecurity tools to  
355    be deployed within an isolated environment.

356    Within this architecture, the BAD capability is introduced in two areas that use four  
357    collaborator products. Two BAD systems are installed within the demonstration  
358    environment's DMZ. One of these BAD systems is agent-based and is installed at multiple  
359    endpoints within the CRS and the PCS, while data is aggregated at the demonstration  
360    environment's DMZ. The other BAD system is implemented as an additional capability to  
361    the historian within the CRS only. This build consisted of performing and introducing the  
362    BAD capability into the CRS and PCS environments, one product at a time. In other words,  
363    only one product was installed and performing BAD at any given time. Each collaborator's  
364    product installation was scheduled to run in sequence to ensure complete autonomy from  
365    each product in the build.

366 **Figure 3-1 BAD High-Level Architecture**



367

### 368 **3.1. Collaborative Robotic System**

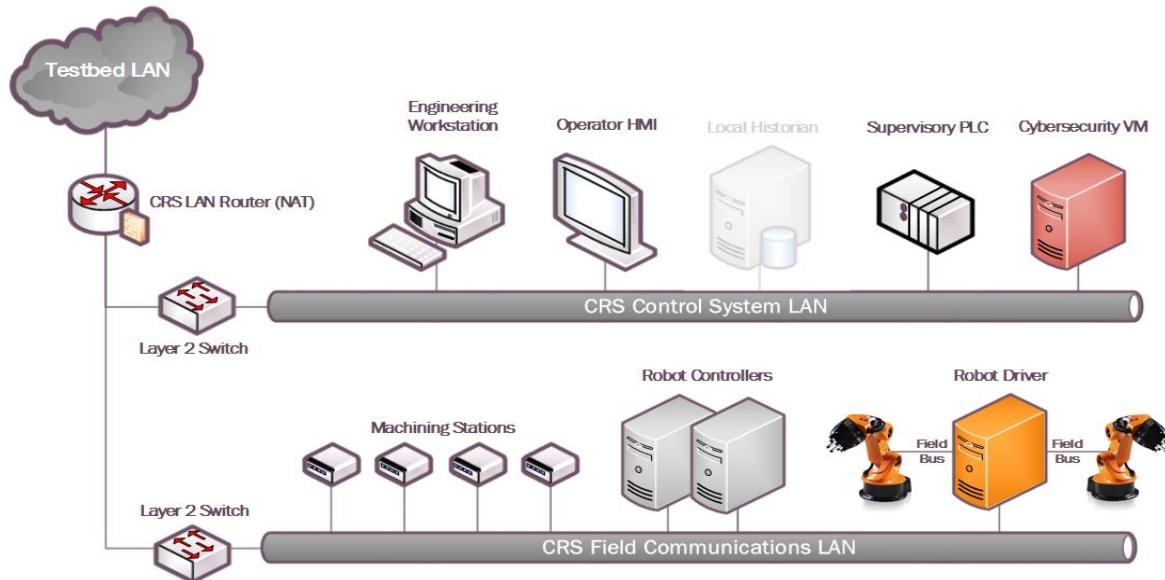
369 The CRS enclave of the environment is composed of two robotic arms that emulate a  
 370 material-handling application known as “machine tending” [8]. Robotic machine tending  
 371 uses robots to interact with the machinery, performing operations that a human operator  
 372 would normally perform (e.g., loading and unloading parts, opening and closing machine  
 373 doors, activating operator control-panel buttons). The robots operate in concert according to a  
 374 material-handling procedure that changes dynamically based on feedback from the simulated  
 375 machining operations. An architecture of the robotic enclave network is shown in Figure 3-2.

376 The robot controllers can operate in one of two modes: deployed or virtualized. In the  
 377 deployed mode, each robot is controlled on a dedicated Dell PowerEdge R420 server running  
 378 the robot operating system (ROS) on top of Ubuntu Linux. In the virtualized mode, each  
 379 robot is controlled by virtualized servers within a hypervisor running on a Dell PowerEdge  
 380 620 server. The deployed mode supports experiments with a pseudo-ideal configuration. The  
 381 virtualized mode supports experiments with a resource-restricted configuration and can  
 382 maintain independent demonstration environments.

383 The pseudo-ideal configuration provides the robot controller software with computational  
 384 resources that are well beyond the minimum requirements for unimpeded operations.  
 385 Operating in this manner is reserved for experiments that do not require server performance  
 386 impacts to be measured (e.g., network-specific experiments). The resource-restricted  
 387 configuration allows the researchers to restrict the available resources to the robot controller  
 388 software and underlying OS (e.g., memory allocation, available hard-disk space, hard-disk  
 389 access rates, number of central processing unit [CPU] cores).

390 The hypervisor also allows software-based cybersecurity tools to be deployed within an  
391 isolated environment, and allows for the ability to restore the enclave environment to a  
392 known-good state, reducing the chances of cross-contamination by residual software modules  
393 or services remaining within a virtual machine (VM) post-experiment. Software-based  
394 cybersecurity tools are installed on VMs dedicated to specific experiments within the  
395 hypervisor and are archived. This allows any tool to be recalled for any experiment that  
396 requires its execution.

397 **Figure 3-2 Robotic Assembly Enclave Network**



398

### 399 **3.1.1. CRS Network Architecture**

400 In addition to the two industrial robots, the enclave includes a supervisory programmable  
401 logic controller (PLC), a human-machine interface (HMI), several servers for executing  
402 required computational resources and applications, a cybersecurity virtual machine  
403 (CybersecVM), and an engineering workstation.

404 The CRS enclave LAN is constructed as a hierachal architecture. For the BAD  
405 implementation, the reconfigurable design of the enclave enabled the implementation of  
406 network segmentation and security perimeters. The local network traffic (CRS LAN) is  
407 managed by a Siemens RUGGEDCOM RX1510, and the high-level environment traffic  
408 (environment LAN) and its connection to the “corporate network” are managed by a Cisco  
409 ASA 5512-X.

410 The CRS LAN has numerous machines that directly operate and support the operation of the  
411 enclave. The robot controllers or driver servers execute the operational code and  
412 communicate directly with the robots to direct their actions. The supervisory PLC  
413 communicates the status of the machining stations and operator controls to the robot  
414 controllers, and of part tracking for manufacturing performance measurements. The operator  
415 HMI also communicates with the PLC to display manufacturing process information and  
416 performance measurements to the operator. The engineering workstation hosts the  
417 programming environment and debugging tools that are used to modify the robot code and to

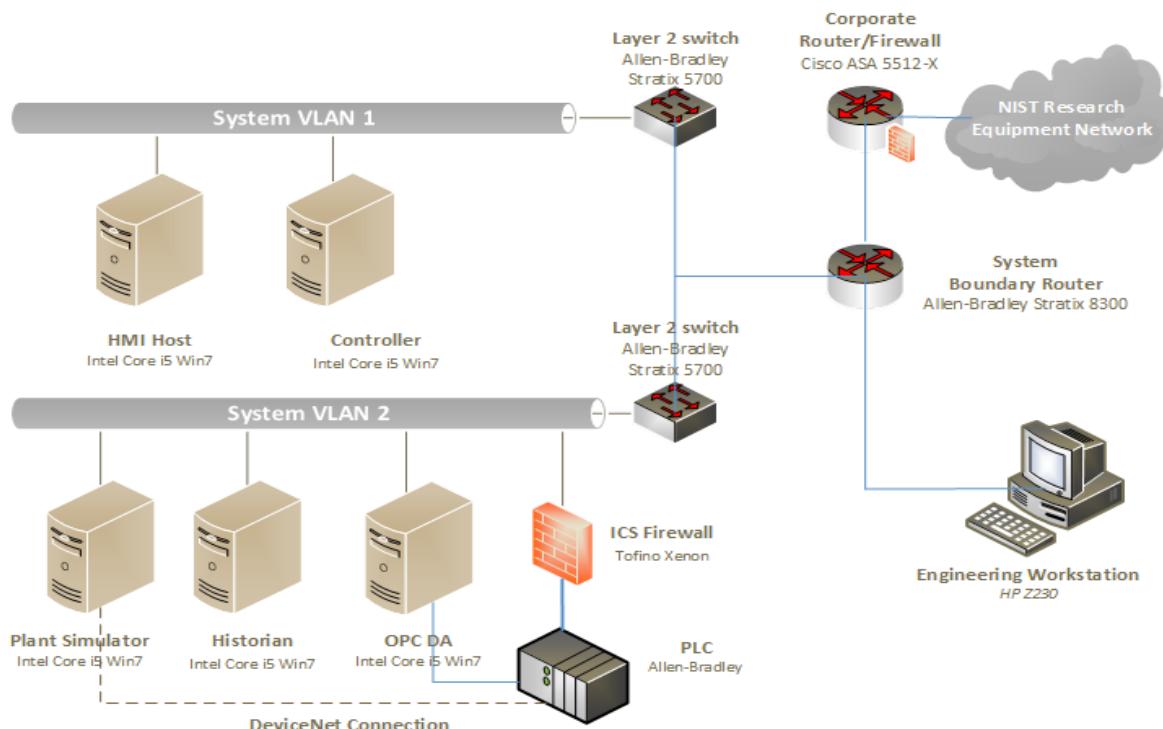
418 give terminal-level access to other machines within the enclave. The HyperV server provides  
419 server virtualization to the enclave, allowing researchers to create servers on demand, as  
420 required by specific software tools or packages.

421 **3.2. Process Control System**

422 The PCS enclave emulates an industrial continuous manufacturing system, a manufacturing  
423 process to produce or process materials continuously, where the materials are continuously  
424 moving, going through chemical reactions, or undergoing mechanical or thermal treatment.  
425 Continuous manufacturing usually implies a 24/7 (24 hours a day, seven days a week)  
426 operation with infrequent maintenance shutdowns and is contrasted with batch  
427 manufacturing. Examples of continuous manufacturing systems are chemical production, oil  
428 refining, natural-gas processing, and wastewater treatment [9]. An architecture of the PCS  
429 network is depicted in Figure 3-3.

430 **Figure 3-3 PCS Network Architecture**

### Process Control System Network Diagram



431

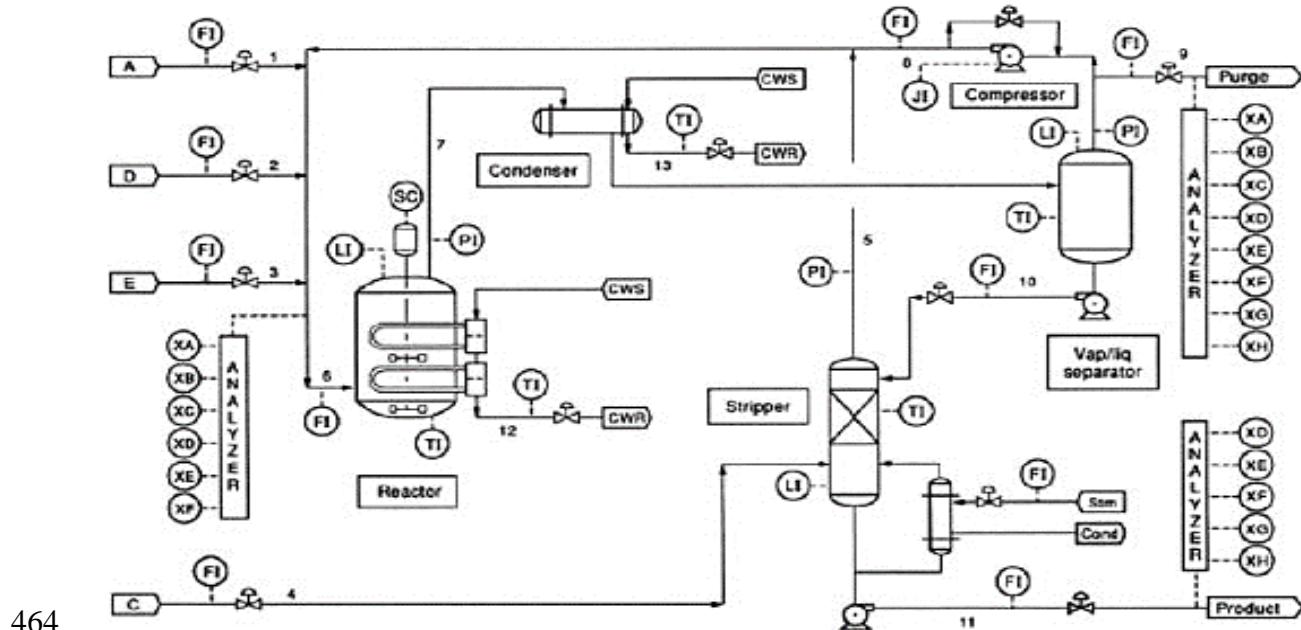
432 The PCS includes a software simulator to emulate the Tennessee Eastman (TE) chemical  
433 reaction process. The TE problem, presented by Downs and Vogel [10], is a well-known  
434 process-control problem in continuous chemical manufacturing. The TE control problem was  
435 chosen as the continuous process model for several reasons. First, the TE model is a  
436 well-known plant model that is used in control-systems research, and the dynamics of the  
437 plant process are well understood. Second, the process must be controlled; otherwise,  
438 perturbations will drive the system into an unstable state. The inherent unstable open-loop

439 operation of the TE process model presents a real-world scenario in which a cybersecurity  
 440 attack could represent a real risk to human safety, environmental safety, and economic  
 441 viability. Third, the process is complex, nonlinear, and has many degrees of freedom by  
 442 which to control and perturb the dynamics of the process. Finally, numerous simulations of  
 443 the TE process have been developed with readily available reusable code. We chose the  
 444 University of Washington Simulink controller design by Ricker [11]. The Ricker Simulink  
 445 model was chosen for its multiloop control architecture, making distributed control  
 446 architectures viable. It accurately matches the Downs and Vogel model, and the control code  
 447 is easily separable from the plant code.

448 The TE process model is illustrated in Figure 3-4. Downs and Vogel did not reveal the actual  
 449 substances used in the process; instead, they used generic identifiers for each substance. The  
 450 process produces two products (G and H) from four reactants (A, C, D, and E). The process  
 451 is defined as irreversible and exothermic, and the reaction rates of the four reactants are a  
 452 function of the reactor temperature. The process is broken down into five major operations: a  
 453 reactor, a product condenser, a vapor-liquid separator, a product stripper, and a recycle  
 454 compressor. The PCS is housed in a 19-inch rack system. The model has 12 actuators for  
 455 control and 41 sensors for monitoring. The process description is summarized below.

456 As previously mentioned, the reaction rates of the reactants are a function of the reactor  
 457 temperature. The gaseous reactants are combined in the reactor to form liquid products. The  
 458 reactor temperature is then cooled by using an internal cooling bundle. The reactor product  
 459 passes through the condenser to the separator. The vapor-liquid separator then separates  
 460 unreacted gases from the liquid products. The unreacted gases are sent back to the reactor by  
 461 the recycle compressor. The remaining reactants are removed in a stripping column. Finally,  
 462 the two end products are sent downstream for further refining and separation.

463 **Figure 3-4 TE Process Control Model**



465    **3.2.1. PCS Network Architecture**

466    The PCS includes a software simulator to emulate the TE chemical reaction process. The  
467    simulator is written in C code and is executed on a computer running Windows 7. In  
468    addition, the system includes a PLC, a software controller implemented in MATLAB, an  
469    HMI, an object linking and embedding for process control (OPC) data access (DA) server, a  
470    data historian, an engineering workstation, and several virtual LAN switches and network  
471    routers.

472    The PCS network is segmented from the demonstration network via a boundary router. The  
473    router is using a dynamic routing protocol, Open Shortest Path First, to communicate with  
474    the main demonstration environment router. All network traffic needs to go through the  
475    boundary router to access the main demonstration network. There are two virtual network  
476    segments in the system. Each network is managed by an Ethernet switch. The HMI and the  
477    controller are in Virtual Local Area Network (VLAN)-1, while the plant simulator, data  
478    historian, OPC DA server, and PLC are in VLAN-2. VLAN-1 simulates a central  
479    control-room environment in which the HMI and the controllers are virtually located in the  
480    same network segment. VLAN-2 simulates the process operation environment, which  
481    typically consists of the operating plant, PLCs, OPC DA server, and data historian. These  
482    network switches and routers are highly reconfigurable and therefore allow the system to  
483    implement various network topologies for demonstration.

484    A Tofino Xenon security appliance, a firewall specially designed for ICS application, is  
485    installed to protect the PLC. The firewall rules are configured to allow only certain network  
486    nodes and specific protocols to access the PLC, and to deny all other traffic. All of the  
487    computer nodes in the system have the Windows firewall enabled. Rules are configured to  
488    allow computer access to only traffic specific to their applications. For example, the firewall  
489    of the OPC DA server computer allows only a restricted range of remote procedure call and  
490    Distributed Component Object Model (DCOM) ports for the OPC clients to access, and it  
491    restricts the source Internet Protocol (IP) address of the OPC clients.

492    The plant simulator is implemented in C code, which was based on the Fortran code  
493    originally developed by Downs and Vogel. The plant simulator requires a controller to  
494    provide a control loop in order to operate continuously. A decentralized controller  
495    implemented in Simulink, developed by Ricker, is used as the process controller. The Ricker  
496    implementation accurately matches the plant simulator, and the controller is a separate  
497    software process that runs on a separate computer from the plant simulator. To provide  
498    communication between the plant simulator and the controller, a hardware PLC with an  
499    industrial network protocol capability is used. The industrial network protocol is used to  
500    communicate between the plant simulator and the PLC. The plant simulator sends its sensor  
501    information to the controller, and the controller algorithm uses the sensor inputs to compute  
502    the desired values of the actuators and then sends those values back to the plant simulator.

503    In the plant simulator computer, a multinode DeviceNet card was installed. DeviceNet is a  
504    common industrial protocol that is used in the automation industry to exchange data between  
505    control devices. The multinode card allows a single hardware device to emulate multiple  
506    virtual DeviceNet nodes. In this case, each sensor and actuator point are dedicated nodes.  
507    Therefore, 53 virtual nodes (41 for sensors and 12 for actuators) were configured in the

508 system. A software interface was developed to send and receive sensor and actuator values  
509 between the plant simulator and the PLC, through DeviceNet. An OPC DA server is running  
510 on a Windows 7 computer, acting as the main data gateway for the PLC. The PLC  
511 communicates to the OPC DA server to update and retrieve all of the sensor and actuator  
512 information, respectively. This sensor and actuator information is also known as a “tag” in  
513 PLC terminology. The controller has a MATLAB Simulink interface that directly  
514 communicates with the OPC DA server.

515 An HMI and a data historian are implemented in the system. The HMI provides a graphical  
516 user interface (GUI) to present information to an operator or user about the state of the  
517 process. The data historian serves as the main database to record all of the process sensor and  
518 actuator information. Both the HMI and the data historian have built-in interfaces to establish  
519 connections to the OPC DA server to access all of the process information. An engineering  
520 workstation is used in the system for engineering support, such as PLC development and  
521 control, HMI development and deployment, and data-historian data retrieval.

522 All systems in the PCS are synchronized with the NTP server environment. A network  
523 packet analyzer tool is installed in all of the computers in the system to capture and analyze  
524 network packets. Other specialized software tools are also used to monitor the system. For  
525 example, an OPC data analyzer is used to monitor OPC data exchange, and DeviceNet  
526 logging is used to log DeviceNet-level traffic.

### 527 **3.3. Behavioral Anomaly Detection Capabilities Demonstrated**

528 The BAD capability was demonstrated by installing single products into each environment.  
529 Only one product was installed and performing BAD at any given time. The BAD capability  
530 is achieved by three different detection methods: network-based, agent-based, and  
531 historian/sensor-based. CyberX and SecurityMatters SilentDefense demonstrated  
532 network-based detection. Secure-NOK’s SNOX Detector demonstrates agent-based  
533 detection. The OSIsoft Process Information (PI) System’s PI Data Archive (historian)  
534 demonstrates sensor-based detection from historian data.

#### 535 **3.3.1. SecurityMatters SilentDefense**

536 SecurityMatters SilentDefense utilizes sensors to passively sniff traffic at the Layer 3 peer-  
537 to-peer switches to monitor critical networks for anomalies. The SilentDefense product also  
538 uses a command center to manage and collect data from all sensors at an enterprise site. The  
539 installation and configuration procedures undertaken for the SecurityMatters SilentDefense  
540 product are provided in Appendix A.

#### 541 **3.3.2. Secure-NOK SNOX**

542 Secure-NOK’s SNOX is a cybersecurity monitoring and detection system tailored for  
543 industrial networks and control systems. SNOX utilizes nonintrusive endpoint monitoring  
544 agents and passive network monitoring from Layer 2 and Layer 3 switches. The SNOX  
545 network intrusion detection system (IDS) comes preinstalled on an appliance, and endpoint  
546 monitoring agents are integrated into the asset owner’s environment. The installation and  
547 configuration procedures undertaken for the Secure-NOK SNOX appliance are provided in  
548 Appendix B.

549 **3.3.3. CyberX**

550 The CyberX platform delivers continuous operational technology (OT) threat monitoring and  
551 asset discovery, combining a deep understanding of industrial protocols, devices, and  
552 applications with OT-specific behavioral analytics, threat intelligence, risk and vulnerability  
553 management, and automated threat modeling. The platform is delivered as a preconfigured  
554 appliance, including the IP address, subnet mask, default gateway, and Domain Name  
555 System (DNS) servers utilized in the build environment. The installation and configuration  
556 procedures undertaken for the CyberX appliance are provided in Appendix C.

557 **3.3.4. OSIsoft PI Data Archive**

558 The OSIsoft PI System's PI Data Archive is a component of the PI System that retrieves,  
559 archives, and enables high-performance data storage and rapid retrieval by using minimal  
560 disk space. The installation and configuration procedures undertaken for OSIsoft's PI System  
561 software are provided in Appendix D.

562 **3.4. Behavioral Anomaly Detection Methods and Security Functions**

563 Table 3-1 identifies methods used in this project and provides a mapping between the method  
564 type, the function performed, and the security control(s) provided. Refer to Table 2-1 for an  
565 explanation of the Cybersecurity Framework subcategory codes.

566 **Table 3-1 BAD Methods and Security Functions**

Type	Function	CSF Subcategories
Network-based	Identifies, monitors, and reports anomalous ICS traffic that might indicate a potential intrusion. Collects ICS network traffic via passive (agentless) monitoring. The system uses deep packet inspection to dissect traffic from both serial and Ethernet control network equipment.	DE.AE-1, DE.AE-2, DE.AE-5, DE.CM-1, DE.CM-4, DE.CM-7, DE.DP-4
Historian/sensor-based	Gathers raw data, records process data, and creates calculations. Provides monitoring and performance alerts of the process historian. The historian accesses historical data and consolidates it with current, real-time data. It allows for investigating intermittent issues, troubleshooting equipment failures, comparing current versus past production performance, and measuring new-plant startups against existing facilities.	Does not support a NIST Cybersecurity Framework subcategory in and of itself. It provides the data to be monitored by the ICS behavior monitor (next item).  Related subcategories: DE.AE-5, DE.CM-1

Type	Function	CSF Subcategories
Agent-based	Identifies, monitors, and reports anomalous ICS traffic that might indicate a potential intrusion. Uses nonintrusive software agents to monitor the ICS network that requires no updating. The network IDS passively collects data from the ICS / Supervisory Control and Data Acquisition (SCADA) network via Switch Port Analyzer (SPAN)/mirroring ports. The nonintrusive host-monitoring agents collect data from within endpoints. The agents send event information to the detector, which looks for early warnings of cybersecurity attacks, and alerts on the anomalies detected by using a web interface.	DE.AE-1, DE.AE-2, DE.AE-5, DE.CM-1, DE.CM-4, DE.CM-7, DE.DP-4

567

### 568 3.5. Typographic Conventions

569 Table 3-2 presents the typographic conventions used in this NISTIR's descriptions of  
 570 scenarios and demonstration findings.

571 **Table 3-2 Typographic Conventions**

Typeface/Symbol	Meaning	Example
<i>Italics</i>	file names and path names; references to documents that are not hyperlinks; new terms; and placeholders	For detailed definitions of terms, see the <i>CSRC Glossary</i> .
<b>Bold</b>	names of menus, options, command buttons, and fields	Choose <b>File &gt; Edit</b> .
Monospace	command-line input, on-screen computer output, sample code examples, and status codes	<code>Mkdir</code>
<b>Monospace Bold</b>	command-line user input contrasted with computer output	<b>service sshd start</b>
<u>blue text</u>	link to other parts of the document, a web Uniform Resource Locator (URL), or an email address	All publications from NIST's NCCoE are available at <a href="https://www.nccoe.nist.gov">https://www.nccoe.nist.gov</a> .

572 **4. Demonstration Scenarios and Findings**

573 With both the robotic and process-control infrastructures available for immediate use, the  
 574 implementation of the BAD capabilities consisted of installing and integrating a single tool  
 575 with the existing infrastructures. The BAD products are installed within the demonstration  
 576 environment's DMZ of the existing infrastructure.

577    **4.1. Network-Based Behavioral Anomaly Detection**

578    Network-based anomaly detection requires the aggregation of all network traffic into a single  
579    collection point. Multiple appliances can also be used with centralized management to collect  
580    network traffic data from different zones and sites. Network traffic is examined and  
581    compared with a preexisting baseline, which is assumed to be normal at the time that it is  
582    captured. Should the network traffic show deviations from this baseline or show any other  
583    types of behavior considered suspicious or unauthorized, an alert will be generated based on  
584    preconfigured parameters.

585    During network-based anomaly detection, network traffic from the CRS and PCS LAN  
586    networks is aggregated at the demonstration environment's DMZ via SPAN ports. At the  
587    demonstration environment's DMZ, the traffic is inspected by the CyberX and SilentDefense  
588    platforms. Once a baseline of network traffic is established as normal, this aggregation of  
589    traffic can show deviations from the baseline, triggering an alert based on preconfigured  
590    parameters. Parameters can be configured to trigger alerts relating to network-traffic  
591    deviations, user-behavior deviations, volumetric deviations, and protocol deviations.

592    **4.2. Agent-Based Behavioral Anomaly Detection**

593    Agent-based anomaly detection combines some of the features of network-based anomaly  
594    detection with the nonintrusive monitoring of endpoints. Agent-based anomaly detection uses  
595    distributed software agents installed onto or close to devices, such as servers, HMIs, network  
596    switches, and controllers. Agents collect and preprocess device information, such as the use  
597    of removable media; logged-in users; ingress/egress traffic; device configurations; process  
598    and program details; and device parameters, such as memory, disk, and processor utilization.  
599    The collected information is sent securely to a detection engine. The detection engine alerts  
600    on deviations from preconfigured security policies and preexisting baselines. The preexisting  
601    baselines are reviewed and accepted as normal at the time that they are captured.

602    During agent-based anomaly detection, the behavior of Windows 7 devices in the PCS  
603    network, and of Ubuntu Linux devices in the CRS network, was monitored. The host agent  
604    information and network traffic are inspected by the Secure-NOK SNOOK Detector. Once a  
605    baseline of the device configuration and behaviors is established as normal, deviations will  
606    trigger alerts.

607    **4.3. Historian-Based and Sensor-Based Behavioral Anomaly Detection**

608    Operational historian/sensor-based anomaly detection relies on the collection of sensor data  
609    into ICS network components, such as operational historians. Because historians are  
610    constantly being fed real-time operational data, which has already been configured within  
611    operational bounds, or set points, any deviations from these thresholds will produce an alert  
612    that can be captured. Typically, this would be considered an operational anomaly. OSIsoft's  
613    PI Data Archive performs historian/sensor-based detection.

614    **4.4. Demonstration Results and Findings**

615    The demonstration effort examined 16 classes of BAD. These 16 classes for which  
616    anomalous events were successfully detected include the detection of the following items:

- 617        • plaintext passwords
- 618        • user authentication failures
- 619        • new network devices
- 620        • abnormal network traffic between devices
- 621        • internet connectivity
- 622        • data exfiltration
- 623        • unauthorized software installations
- 624        • PLC firmware modifications
- 625        • unauthorized PLC logic modifications
- 626        • file transfers between devices
- 627        • abnormal ICS protocol communications
- 628        • malware
- 629        • denial of service (DoS)
- 630        • abnormal manufacturing system operations
- 631        • port scans/probes
- 632        • environmental changes

633    Each of the demonstration events addressed threats that would not normally be detected by  
634    current security tools that involve monitoring system behaviors for predefined out-of-  
635    specification settings or readings or that involve threat signatures (information elements  
636    previously identified as being associated with threats or vulnerability characteristics, such as  
637    with an IDS or an intrusion protection system). Network-based, agent-based, and  
638    historian/sensor-based detection capabilities were examined. Each product that was  
639    demonstrated performed as expected.

640    As indicated in Section 4.1, individual products were examined in different scenarios, and  
641    not all types of detection events were examined in each scenario. As a result, no comparison  
642    of product detection capabilities can usefully be made or is appropriate to this NISTIR.

643    The installation, configuration, anomaly scenarios, and results for each tool are described in  
644    the appendixes of this document.

645    **5. Conclusion**

646    The goal of this project was to demonstrate BAD techniques that businesses can implement  
647    and use to strengthen the cybersecurity of their manufacturing processes. The BAD project  
648    demonstrated three different detection methods: network-based, agent-based, and operational  
649    historian/sensor-based. We have shown that BAD techniques can serve as a key security  
650    component in sustaining ICS operations. This NISTIR illustrates the use of the different  
651    BAD capabilities, to provide a better understanding of what each of the techniques offers and  
652    how to apply each of these techniques in different ICS network environments.

653 **Appendix A. SecurityMatters SilentDefense Supplemental Information**

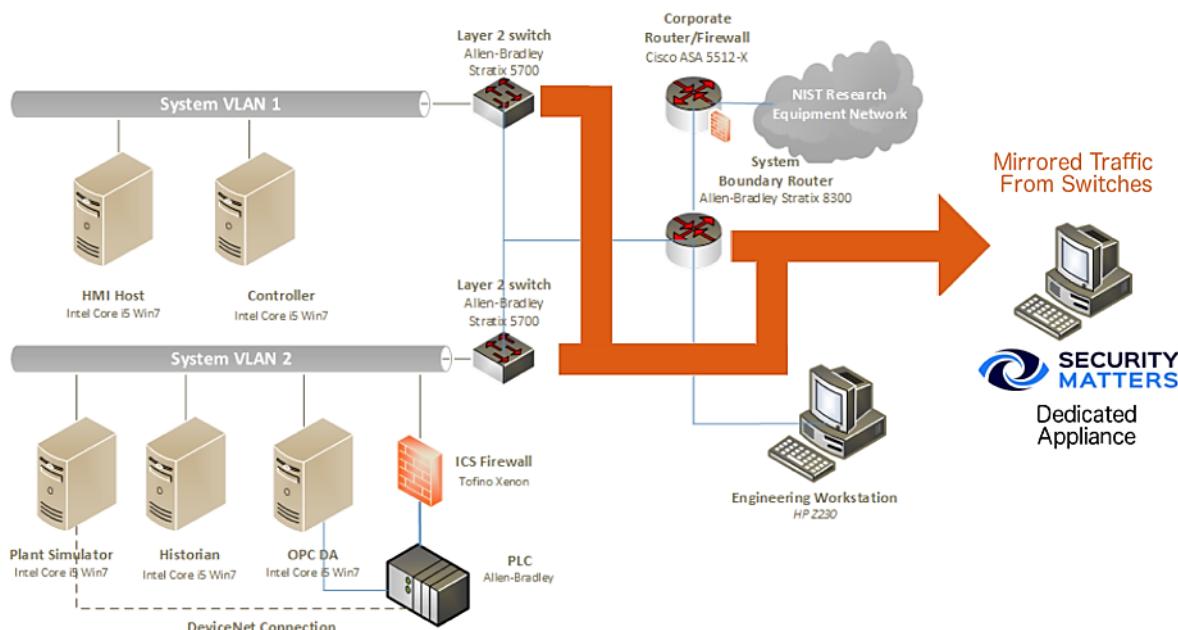
654 SecurityMatters SilentDefense utilizes sensors to passively sniff traffic at the Layer 3 peer-  
655 to-peer switches to monitor critical networks for anomalies. The SilentDefense product also  
656 uses a command center to manage and collect data from all network-based sensors within a  
657 manufacturing system.

658 **A.1. Build Architecture**

659 The SilentDefense dedicated appliance was physically installed in the measurement rack of  
660 the Cybersecurity for Smart Manufacturing Systems (CSMS) environment. Three existing  
661 Switch Port Analyzer (SPAN) ports from each system (collaborative robotic system [CRS]  
662 and process control system [PCS]) were connected to dedicated network interfaces on the  
663 appliance, for a total of six SPAN ports. The SPAN port connections to the appliance, within  
664 the PCS and CRS networks, are shown in Figure A-1 and Figure A-2, respectively.

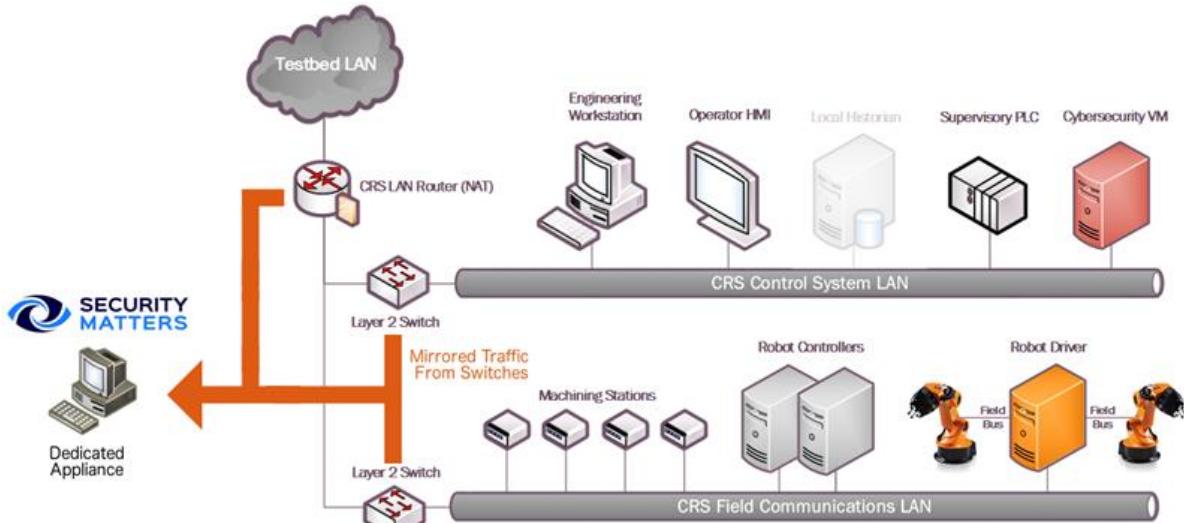
665 The appliance network connection was connected to the demilitarized zone (DMZ) network  
666 located in the test bed's measurement rack, to isolate the appliance's network traffic from the  
667 rest of the network. Engineering laptops were used to interface with the SilentDefense  
668 graphical user interface (GUI) via network connections to the DMZ. More information  
669 regarding the specific configuration of the test-bed network can be found in Section 3.

670 **Figure A-1 SPAN Port Connections to the SilentDefense Appliance in the PCS**



671

672 **Figure A-2 SPAN Port Connections to the SilentDefense Appliance in the CRS**



673

## 674 **A.2. Installation and Configuration**

675 Physical hardware and software were provided by SecurityMatters for this demonstration.  
676 After the hardware appliance was received, it was installed into the CSMS test bed. Soon  
677 after the initial installation, engineers from SecurityMatters arrived on site to complete the  
678 installation and configuration of the tool. The following subsections describe the steps taken  
679 to install and configure the appliance.

### 680 **A.2.1. Hardware**

681 The SilentDefense appliance was installed as a bundle (with the sensor and the command  
682 center on the same hardware). Typically, these functions are separated in production  
683 installations; however, because this was a lab system, the bundle was sufficient for the  
684 demonstration environment. The bundled hardware was a Dell R630 1U Rackmount Server  
685 with the following specifications:

- 686 • central processing unit (CPU): Intel Xeon E5-2620, 2.4 gigahertz, 5-megabyte (M)  
687 cache, 6C/12T (6 cores and 12 threads)  
688 • random-access memory: 32 gigabytes (GB), registered dual in-line memory module,  
689 2,400 megatransfers per second  
690 • hard drive: 800 GB, solid-state drive  
691 • redundant array of independent disks controller: PERC H730, 1 GB cache  
692 • sniffing network interface card (NIC): Intel i350 Quad Port Peripheral Component  
693 Interconnect Express Card

### 694 **A.2.2. Operating System**

695 SilentDefense 3.11.1 uses the Ubuntu 16.04.3 Long-Term Support (LTS) Server operating  
696 system (OS), which is modified with two scripts. First, there is a SecurityMatters OS update  
697 script to update libraries to the latest versions and to install some new libraries necessary for  
698 SilentDefense operation. The OS is then modified with a main-configuration script, which

699 hardens the OS by performing operations, such as disabling users, setting iptables, and  
700 setting the update repository addresses to local hard-drive folders (so that, automatic updates  
701 are not from the internet). The steps for modifying the OS are as follows:

- 702 1. Install the Ubuntu 16.04.3 LTS Server OS.
- 703 2. Run the SilentDefense OS by using the following command:

```
704 sudo ./update_os_16.04.3_to_29.11.2017.run
```

- 705 3. Reboot the system by using the following command:

```
706 sudo reboot now
```

- 707 4. Run the SilentDefense main-configuration script by using the following command:

```
708 sudo ./main_configuration_29.11.2017.run
```

#### 709 A.2.3. Configure Sniffing Ports

710 The Intel i350 card has four sniffing ports to configure. This configuration is done through  
711 the SilentDefense `sdconfig` utility:

- 712 1. Run the SilentDefense configuration utility by using the following command:
- 713 

```
sudo sdconfig
```
- 714 2. Choose the option **Configure New Monitoring Interface**.
- 715 3. Select the four Intel i350 NIC interfaces by using the space bar on your keyboard.
- 716 4. Click **OK**.
- 717 5. Choose the option **Exit this configuration Utility**.

#### 718 A.2.4. Configure the Management Port Internet Protocol Address

719 The SilentDefense system has a management port that is used to connect to the sensors and  
720 for the SilentDefense administrators and analysts to access the system GUI. This  
721 configuration is done through the SilentDefense `sdconfig` utility:

- 722 1. Run the SilentDefense configuration utility by using the following command:
- 723 

```
sudo sdconfig
```
- 724 2. Choose the option **Remove management interface configuration**.
- 725 3. Choose the option **Configure management interface**.
- 726 4. Type in the following information:
  - a. **IP address** (Internet Protocol address)

- 728           **b. subnet mask**  
729           **c. gateway**  
730           **d. Domain Name System server(s)**

731       5. Press **OK**.

#### 732     **A.2.5. Configure the SPAN Ports on Layer 3 Network Switches**

733     The SilentDefense passive monitoring system uses SPAN ports to intercept and analyze  
734     network packets. The process to configure a SPAN port varies among different makes and  
735     models of networking hardware. For SPAN port configuration information, consult the  
736     current configuration manual or user guide for the specific networking hardware.

#### 737     **A.2.6. Log into SilentDefense**

738     The SilentDefense GUI has a default username and password of `admin`. Upon the first login,  
739     you are required to change the password to something more secure. The SilentDefense  
740     software will not allow the new username and password to be the same.

741       1. Browse to the SilentDefense GUI from a web browser, using the following Uniform  
742       Resource Locator (URL):

743           `https://<mgmt_ip_address>`

744       2. Type the username `admin` and the password `admin` in the login fields, and then click  
745       **Sign in**.

746       3. A new window pops up, requiring you to change the password. Type in a new  
747       password that meets the following requirements:

748           a. Contains eight characters minimum

749           b. Does not contain the account name

750           c. Contains at least three character groups (e.g., uppercase, lowercase, number,  
751           special)

752       4. Click **Apply**.

753       5. The dashboard now appears, and you can begin to use SilentDefense.

#### 754     **A.3. Anomaly Scenarios**

755     The network-based anomaly detection method was demonstrated for the scenarios detailed in  
756     the following subsections. Each scenario includes a description of the anomaly, a detailed  
757     description of how each demonstration event was conducted in the CSMS environment, and  
758     the observed results.

759 For the sake of brevity, only a subset of the alerts observed during each anomaly scenario is  
760 shown. However, each anomaly scenario includes a screenshot of the alerts summary (or  
761 aggregated summary) observed after the anomaly scenario had completed.

### 762 A.3.1. Unencrypted Passwords Are Used to Access a Networking Device

763 Unencrypted or plaintext passwords transmitted over a network are a vulnerability for  
764 industrial control system (ICS) networks. If packets containing these credentials are  
765 intercepted, then the passwords can be easily unmasked and can be used to obtain  
766 unauthorized access to devices or services that use those credentials. This vulnerability can  
767 be amplified if multiple devices utilize the same credentials.

768 This anomaly was executed on the PCS. The network switches and router provide a Telnet  
769 service for remote management. This protocol transmits user credentials as plaintext. A  
770 Telnet connection was opened between the engineering workstation and Virtual Local Area  
771 Network (VLAN)-1 by using the open-source PuTTY [12] client.

The screenshot shows the SilentDefense™ software interface. At the top, there are tabs for Dashboard, Network, Events, Sensors, Settings, and admin. Below the tabs, there are buttons for Alert details, Back, Edit, Delete, Show | v, Download pcap, and Help. The main area is divided into three panels: Summary, Source host info, and Alert details. The Summary panel contains fields like Alert ID (3270), Timestamp (Dec 7, 2017 14:50:04), Sensor name (Local), Detection engine (Industrial threat library (ITL)), and ID and name (id\_secp\_telnet - Use of insecure protocol (TELNET)). The Source host info panel lists IP address (172.16.3.10 (Private IP)), Host name (fgs-47631ehh.lan.lab), MAC addresses (E4:90:69:3B:C2:C4 (Rockwell), 40:AB:F0:3D:48:AE (HewlettP), E4:90:69:3B:C2:C5 (Rockwell)), Role (Master), Other roles (Windows workstation, Terminal client), Vendor/model (Rockwell), and OS version (Windows 7 or Windows Server 2008 R2). The Client protocol(s) panel lists various protocols: DCOM (TCP 135, 49158, 49187, 49188), DNS (UDP 53, 53535), ETHIP (TCP 44818), HTTP (TCP 80, 8530), Kerberos (TCP 88), LDAP (TCP 389), LDAP (UDP 389), NTP (UDP 123), NetBIOS (UDP 137), NoData (TCP 56224, 56614, 58847), NotAKnowOne (TCP 1332, 3060, 3389), NotAKnowOne (UDP 3702), RDP (TCP 3389), SMB (TCP 445), SMB (UDP 138), SSDP (UDP 1900), SSH (TCP 22), SSL (TCP 443, 3389), and Syslog (UDP 514). The Alert details panel notes: "Note: this alert is raised only once per 24 hours per source/destination host combination". At the bottom left, there is a link to "Alerts / Alert details". On the right, there is a copyright notice: "Copyright (C) 2009-2017 SecurityMatters (v.3.11.1)".

Date	Destination host	Protocol	Source IP	Source Port	Destination Port	Status
Dec 7, 2017 14:50:04	Destination host not... Local	Com...	172.16.3.10 (fg...	23	23 (TCP)	TELNET
Dec 7, 2017 14:50:04	Use of insecure protoc...	Indu...	-	-	Not analyzed	H

772

773

### 774 A.3.2. Transmission Control Protocol Connection Requests Are Received from 775 the Internet

776 When attempting to form a connection by using the transmission control protocol (TCP), a  
777 connection request first must be sent to the server. If a TCP connection request is received  
778 from the internet (i.e., it has a public Internet Protocol [IP] address), then this can indicate a  
779 network misconfiguration, a device misconfiguration, or an unidentified internet connection  
780 within the lower levels of the ICS network.

781 This anomaly was executed on the CRS. The packet manipulation tool Scapy [13] was used  
 782 with Python [14] to create a TCP SYN packet with a public IP as the source address  
 783 (129.6.1.10) and with the programmable logic controller (PLC) IP as the destination address,  
 784 and was injected into the CRS local area network (LAN).

785

Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source IP	Destination IP	Dest. Port
Jan 3, 2018 13:40:05	Communication betwe...	Local	Indus...	-	Not analyzed	■■■■ M	129.6.1.10	192.168.0.30 (p...	80 (TCP)
Jan 3, 2018 13:39:12	Communication betwe...	Local	Indus...	-	Analyzed	■■■■ M	129.6.1.10	192.168.0.30 (p...	80 (TCP)
Jan 3, 2018 13:38:45	Communication betwe...	Local	Indus...	-	Analyzed	■■■■ M	129.6.1.10	192.168.0.30 (p...	80 (TCP)

786

### 787 A.3.3. Data Exfiltration Between ICS Devices via Server Message Block

788 Vulnerable devices within an ICS network can be used as a pivot to bring higher-value  
 789 targets within reach to exfiltrate data (e.g., using a vulnerable Internet of Things device to  
 790 pivot and leverage attacks against a PLC on the same network). Monitoring for abnormal  
 791 communication patterns between ICS devices can help detect these types of attacks,  
 792 especially if the affected devices do not communicate during normal operations.

This anomaly was executed on the PCS. An unauthorized Windows File Share (using the Server Message Block protocol) was configured between the human-machine interface (HMI) server and the engineering workstation. Three types of files were transferred over the share: a comma-separated values (CSV) file, a Microsoft Excel workbook (XLSX) file, and an Adobe Portable Document File (PDF).

SilentDefense™

Dashboard Network Events Sensors Settings

Alert details Back Edit Delete Show | Download pcap

?

Help

Summary

Alert ID	8878
Timestamp	Dec 6, 2017 11:32:28
Sensor name	Local
Detection engine	Industrial threat library (ITL)
ID and name	R1_lec_jub_bfo - Blacklisted file operation
Description	A user has attempted to access a blacklisted file or folder. The defined local security policies whose access should be limited to prevent confidentiality or integrity breaches. Default blacklisted file extensions indicate files which are not supposed to be accessed or transferred in the network because they may pose a security threat, or they may indicate lateral movement of malware or other malicious content.
Severity	<span style="color: red;">!!!!</span> High
Source MAC	E8:00:27:4B:99:58 (PisCompu)
Destination MAC	E4:90:9-3B:C2:C5 (Rockwell)
Source IP	172.16.2.14 (win-fpvdcodcuorlan.lab)
Destination IP	172.16.3.10 (fgr-4763iehhlan.lab)
Source port	56387
Destination port	445
L2 proto	Ethernet
L3 proto	IP
L4 proto	TCP
L7 proto	SMB
Status	Not analyzed
Labels	operations,file_delete
User notes	

Source host info

IP address	172.16.2.14 (Private IP)
Host name	win-fpvdcodcuorlan.lab
MAC addresses	E8:00:27:4B:99:58 (PisCompu) E4:90:9-3B:C2:C5 (Rockwell) E4:90:9-3B:C2:C1 (Rockwell)
Role	Historian
Other roles	Windows workstation, DPC server, DNS server, Web server
Vendor/model	Rockwell
OS version	Windows 7 or Windows Server 2008 R2
DCOM (TCP 133, 49158, 50009, 50010)	
DNS (UDP 53, 53535)	
FTP (TCP 21)	
FTPDATA (TCP dynamic)	
FailedConnection (TCP 80, 50008, 51458, 51463)	
HTTP (TCP 80)	
Kerberos (TCP 88)	
LDAP (TCP 389)	
LDAPS (UDP 389)	
NTP (UDP 123)	
NetBIOS (UDP 137)	
NoData (TCP 50008, 51532, 56228, 60010)	
NotKnownOne (TCP 1332, 5678, 7038, 17211, 26753, 26759, 32153, 36440, 55610)	
NotKnownOne (UDP 42, 1947, 3702)	
SMB (TCP 139, 445)	
SMB (UDP 138)	

Client protocols(s)

DCOM (TCP 135, 50008)	
DNS (UDP 5353)	

Alert details

The following blacklisted file operation has been performed:  
File or folder: \172.16.3.10\EngWorkstation\_Share\testfile\_xmesa7.csv  
Operation: file\_delete  
User: Administrator

The file or folder was matched by the blacklist entry:  
\.csv\\$ (Regex); Operation: 'Read/Write';

Note: this alert is raised only once per 24 hours per source/destination host and filename combination

798

	Date	Action	Location	Type	Source IP	Destination IP	Protocol	Port	Protocol Type
<input type="checkbox"/>	Dec 8, 2017 11:32:28	Blacklisted file operation	Local	Indust...	-	Not analyzed	 H	172.16.2.14 (win-f...	172.16.3.10 (fgs-4... 445 (TCP) SMB
<input type="checkbox"/>	Dec 8, 2017 11:32:28	Blacklisted file operation	Local	Indust...	-	Not analyzed	 H	172.16.2.14 (win-f...	172.16.3.10 (fgs-4... 445 (TCP) SMB
<input type="checkbox"/>	Dec 8, 2017 11:32:15	Application protocol not ...	Local	Comm...	8 - TCP co...	Not analyzed	 M	172.16.2.14 (win-f...	172.16.3.10 (fgs-4... 445 (TCP) SMB
<input type="checkbox"/>	Dec 8, 2017 11:32:15	Successful login using bla...	Local	Indust...	-	Not analyzed	 H	172.16.2.14 (win-f...	172.16.3.10 (fgs-4... 445 (TCP) SMB

799

### 800 A.3.4. Data Exfiltration to the Internet via File Transfer Protocol

801 Attacks against ICS, with the goal of information gathering, must (at some point) attempt to  
802 exfiltrate the data from the ICS network, likely utilizing the internet as a transport  
803 mechanism. Monitoring for ICS devices communicating over the internet can help detect  
804 data exfiltration events, especially if the affected device does not normally communicate over  
805 the internet. Depending on the protocol used for exfiltration, the file contents and/or data  
806 being exfiltrated may be ascertainable (e.g., file names, file types, data transferred using the  
807 File Transfer Protocol [FTP]), providing insight into the impact of the anomaly.

This anomaly was executed on the PCS. An FTP server was installed and configured on a server with an internally routed public IP address (129.6.1.2). The FileZilla FTP client [15] was installed on the historian server and was used to transfer three types of files to the simulated “internet-based” FTP server: a CSV file, an XLSX file, and an Adobe PDF.

812

The screenshot shows a detailed view of a security alert. The 'Summary' tab displays basic information like Alert ID (8859), Timestamp (Dec 8, 2017 11:16:36), and Sensor name (Local). The 'Source host info' tab provides details about the source host, including IP address (172.16.2.14), Hostname (win-fvtddeuer.lan.lab), MAC addresses (E4:90:69:3B:C2:C0, E4:90:69:3B:C2:C1), Role (Historian), and OS version (Windows 7 or Windows Server 2008 R2). The 'Alert details' tab contains a log entry: 'The following blacklisted file operation has been performed: File or folder: testfile\_xmeas7.csv Operation: file\_create User: lossec'. It also notes that the file was matched by a blacklist entry ('.\Csv\\$ (Regex): Operation: Read/Write;') and that the alert is raised only once per 24 hours.

813

### 814 A.3.5. Unauthorized Device Is Connected to the Network

815 It is important to identify all devices on the ICS network, for a complete risk analysis and for  
 816 minimizing potential attack vectors. The detection of unauthorized devices attached to the  
 817 ICS network may indicate anomalous activity. These unauthorized devices are important to  
 818 find and remove, especially because the purpose of an unauthorized device is unknown and  
 819 may be malicious.

820 This anomaly was executed on the CRS. The engineering laptop (Windows 7 OS) was  
 821 removed from the network during the baseline phase of the tool configuration and was later  
 822 connected to the CRS LAN to execute the anomaly. After the initial connection, background  
 823 traffic was automatically generated onto the network by the laptop.

The screenshot shows a detailed view of a network alert. The 'Summary' section includes fields like Alert ID (13407), Timestamp (Dec 12, 2017 09:36:56), Sensor name (Local), Detection engine (Communication patterns (LAN CP)), Profile (9 - UDP communications), Severity (Medium), Source MAC (34:E6:D7:22:C3:ED (Dell)), Destination MAC (FF:FF:FF:FF:FF:FF (Broadcast)), Source IP (192.168.0.147 (knuckles.local)), Destination IP (255.255.255.255), Source port (12309), Destination port (12307), L2 proto (Ethernet), L3 proto (IP), L4 proto (UDP), L7 proto (NotAKnownOne), Status (Not analyzed), Labels, and User notes. The 'Source host info' section provides details about the source host, including IP address (192.168.0.147 (Private IP)), Host name (knuckles.local), MAC addresses (34:E6:D7:22:C3:ED (Dell)), Role (Unknown), Client protocol(s) (DNS (UDP 5353, 5355), NetBIOS (UDP 137), SMB (UDP 138)), Purdue level (4 - Site business network), Criticality (L), Known vulnerabilities (0), Related alerts (16 (Show)), First seen (Dec 12, 2017 09:23:47), and Last seen (Dec 12, 2017 09:49:21). The 'Destination host info' section shows the destination host details, including IP address (255.255.255.255 (Broadcast, Private IP)), MAC addresses (FF:FF:FF:FF:FF:FF (Broadcast)), Role (Broadcast), Server protocol(s) (DHCP (UDP 67), DNS (UDP 53), ETHTP (UDP 44818), NotAKnownOne (UDP 1947, 12307)), Purdue level (4 - Site business network), Criticality (N/A), Known vulnerabilities (0), Related alerts (17 (Show)), First seen (Dec 4, 2017 04:28:15), and Last seen (Dec 12, 2017 09:50:14). The 'Alert Details' section contains the ID and name (lan\_cp\_cnw\_c - Communication pattern not whitelisted), Description (Communication pattern not whitelisted: the source and destination hosts are whitelisted in some communication rule, but not with this combination), and Triggeringrule/default action (alert).

824

Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source IP	Destination IP	Dest. Port	L7 Proto
Dec 12, 2017 09:37:06	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	192.168.0.255	137 (UDP)	NetBIOS
Dec 12, 2017 09:36:56	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	192.168.0.255	138 (UDP)	SMB
Dec 12, 2017 09:36:56	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	255.255.255.255	12307 (UDP)	NotAKnownO...
Dec 12, 2017 09:24:11	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	192.168.0.255	138 (UDP)	SMB
Dec 12, 2017 09:23:58	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	224.0.0.251	5353 (UDP)	DNS
Dec 12, 2017 09:23:56	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	192.168.0.255	137 (UDP)	NetBIOS
Dec 12, 2017 09:23:52	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	255.255.255.255	12307 (UDP)	NotAKnownO...
Dec 12, 2017 09:23:47	Communication patter...	Local	Com...	9 - UDP c...	Not analyzed	Medium	192.168.0.147 (...)	224.0.0.252	5355 (UDP)	DNS

825

### A.3.6. Loss of Communications with Modbus TCP Device

ICS devices must exhibit high availability to support manufacturing operations. This quality becomes more important as the speed of manufacturing operations increases (i.e., short cycle times). If an ICS device hosting a network service becomes unavailable during manufacturing operations, then this may be a sign of anomalous activity and should be investigated. Loss of communications with a device or service may be caused by a multitude of anomalies, including device restarts, software faults, high network utilization, and an increased processing load on the device.

834 This anomaly was executed on the CRS. A firewall rule was added to the Linux iptables  
 835 (Linux kernel firewall) on Machining Station 1 to block all incoming packets on Modbus  
 836 TCP Port 502. The firewall replied with a TCP reset for each incoming packet or connection  
 837 request, to make it appear as is if the Modbus server had terminated and the TCP socket was  
 838 closed.

The screenshot shows the SilentDefense™ software interface. At the top, there's a navigation bar with tabs for Dashboard, Network, Events, Sensors, and Settings. Below the navigation bar, the main area is titled "Alert details". It contains two main sections: "Source host info" and "Destination host info". The "Source host info" section includes fields for IP address (192.168.1.101), Host name (beaglebone-2.local), MAC addresses (94:BB:C5:0E:E1:9F (Ruggedco) B0:D5:CC:FA:70:C9 (TexasIns)), Role (PLC), Other roles (Slave, Web server), Client protocol(s) (Modbus/TCP, HTTP, NTP, DNS, SSH), Server protocol(s) (Modbus/TCP, HTTP, NTP, DNS, SSH), Labels (modbus\_uid=1, modbus\_uid=255), and various status indicators. The "Destination host info" section lists the destination IP (192.168.1.101), port (502), and protocol (TCP). Below these sections, there are tabs for "Summary" and "Monitored networks". The "Monitored networks" tab shows a single entry: RoboticsFieldBusLA\_N with IP 192.168.1.101 and VLAN ID any.

839

Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source IP	Destination IP	Dest. Port	L7 Proto
Dec 11, 2017 11:26:01	MODBUS/TCP device ...	Local	Indus...	-	Not analyzed	■■■■ H	-	192.168.1.101 (...)	-	MODBUSTCP
Dec 11, 2017 11:26:00	Device with many fail...	Local	Indus...	-	Not analyzed	■■■■ L	192.168.0.98 (h...)	192.168.1.101 (...)	502 (TCP)	-

840

### A.3.7. Brute-Force Password Attack Against an ICS Device

841 Authentication systems that are not rate-restricted may be vulnerable to password-guessing  
 842 attacks, especially if the default credentials of the device have not been changed. Compiled  
 843 lists containing default user credentials are freely available on the internet, as are lists of  
 844 commonly used usernames and passwords. Given enough time, an attacker may be able to  
 845 access vulnerable systems by using a brute-force password attack.

846 This anomaly was executed on the CRS. The software Nmap [16] was used to generate the  
 847 brute-force password attack by using the script `http-brute`. The attack was pointed at an  
 848 Apache [17] Hypertext Transfer Protocol (HTTP) server on Machining Station 4, containing  
 849 a directory that was protected by HTTP basic authentication. The HTTP server was not  
 850 configured to limit the number of authentication attempts.

SilentDefense™

Dashboard Network Events Sensors Settings timzim

Alert details Back Edit Delete Show | Download pcap Help

**Summary**

Alert ID	10585
Timestamp	Dec 11, 2017 13:12:40
Sensor name	Local
Detection engine	Industrial threat library (ITL)
ID and name	ht_sec_udb_bored_fail - Login attempt using blacklisted credentials
Description	A user has attempted to login to a system using blacklisted credentials. The login failed but it may be an indication of an attacker trying to use default device credentials to gain access to the system.
Severity	<span style="color:red;">■■■■■</span> High
Source MAC	00:15:D0:04:5B:2B (Microsoft)
Destination MAC	94:88:C5:0E:E1:9F (Ruggedcom)
Source IP	192.168.0.10
Destination IP	192.168.1.104 (station4.lan.lab)
Source port	44436
Destination port	80
L2 proto	Ethernet
L3 proto	IP
L4 proto	TCP
L7 proto	HTTP
Status	Not analyzed
Labels	
User notes	

**Monitored networks**

Name	Address	VLAN IDs
RoboticsFieldBusLAN	192.168.10/24	any
RoboticsControlLAN	192.168.0/24	any

**Source host info**

IP address	192.168.0.10 (Private IP)
MAC addresses	00:15:D0:04:5B:2B (Microsoft) 94:88:C5:0E:E1:9F (Ruggedcom)
Role	Unknown
DNS (UDP 5353)	FailedConnection (TCP 20, 21, 22, 443, 502, 1020, 1021, 1022, 1023, 1024)
Client protocol(s)	HTTP (TCP 80, 5120) SSDP (UDP 1900)
Server protocol(s)	SSH (TCP 22)
Purdue level	4 - Site business network
Criticality	<span style="color:green;">■■■■■</span> L
Known vulnerabilities	0
Related alerts	53 (Show)
First seen	Dec 4, 2017 04:02:29
Last seen	Dec 11, 2017 13:15:15

**Alert details**

Login attempt using blacklisted credentials:  
 Username: root  
 Password: root

Comment:

The credentials listed above are known default credentials for (at least) the following device(s):  
 'Adcon Telemetry addVANTAGE Pro 6.1, 6.5'  
 'Metroliberty NetBeacon Element Management Software'  
 'Moxa Cellular Micro RTU Controller (ioLogik W53xx, ioLogik, IA240/241 Embedded computer'

This is a default blacklist entry

**Destination host info**

IP address	192.168.1.104 (Private IP)
MAC addresses	94:88:C5:0E:E1:9F (Ruggedcom) B0:D5:CC:F4:26:EC (TexasIn)
Role	PLC
Other roles	Slave, Web server
DNS (UDP 5353)	FTP (TCP 21) FTPDATA (TCP dynamic) NTP (UDP 123)
Client protocol(s)	NotAKnownOne (TCP 60723, 60725, 60726, 60727, 60728, 60729, 60730, 60731, 60732, 60734)
Server protocol(s)	FailedConnection (TCP 20, 21, 443) HTTP (TCP 80) MODBUS/TCP (TCP 502) SSH (TCP 22)
Labels	modbus_id=1 modbus_id=255
Purdue level	1 - Process control
Criticality	<span style="color:red;">■■■■■</span> H
Known vulnerabilities	0
Related alerts	226 (Show)
First seen	Dec 4, 2017 04:28:10
Last seen	Dec 11, 2017 13:18:05

852

Filters applied: Today's alerts, By status, Robotics											
n. of agg. details	Event name	Severity	Event-specific info	Protocol	Source IPs	Destination IPs	Destination Sensor - Engine - Profile ports	Min value	Max value	First event	Last event
15	Communication pattern not whitelisted	<span style="color:red;">■■■■■</span> M		IP/TCP/HTTP	192.168.0.10	192.168.1.104 (station4.lan.lab)	80	1 - Local - Communic...		Dec 11, 2017	Dec 11, 2017
11	Login attempt using blacklisted credentials	<span style="color:red;">■■■■■</span> H		IP/TCP/HTTP	192.168.0.10	192.168.1.104 (station4.lan.lab)	80	1 - Local - Industrial th...		Dec 11, 2017	Dec 11, 2017
1	Successful login using blacklisted credentials	<span style="color:red;">■■■■■</span> H		IP/TCP/HTTP	192.168.0.10	192.168.1.104 (station4.lan.lab)	80	1 - Local - Industrial th...		Dec 11, 2017	Dec 11, 2017

853

### 854 A.3.8. Invalid Credentials for Remote Access

855 While it can be expected that some users will accidentally enter invalid credentials on a daily basis, it is important to monitor these events for trends of anomalies. Large quantities of 856 invalid-credential usage may indicate a password-guessing attack. These credentials may also 857 be used to authenticate connections between ICS devices. With the increasing use of remote 858 access for ICS devices, it is important to monitor these services for attempts made by 859 attackers to gain unauthorized access. 860

861 This anomaly was executed on the PCS. A remote desktop session was initialized from the 862 engineering workstation to the HMI server and required authentication with the Microsoft 863 Active Directory service. Invalid credentials were submitted for authentication.

**Alert details**

**Summary**

Alert ID	10571
Timestamp	Dec 11 2017 13:07:14
Sensor name	Local
Detection engine	Communication patterns (LAN CP)
Profile	8-TCP communications
Severity	Medium
Source MAC	F8:B1:56:BA:09:A8 (Dell)
Destination MAC	94:88:C5:0E:E1:9F (Ruggedco)
Source IP	192.168.0.20 (polaris)
Destination IP	192.168.1.101 (beaglebone-2.local)
Source port	50661
Destination port	80
L2 proto	Ethernet
L3 proto	IP
L4 proto	TCP
L7 proto	HTTP
TCP stream opened in hot start mode	false
Status	Not analyzed
Labels	
User notes	

**Source host info**

IP address	192.168.0.20 (Private IP)
Host name	polaris
MAC addresses	F8:B1:56:BA:09:A8 (Dell) 94:88:C5:0E:E1:9F (Ruggedco)
Role	Web server

**Client protocol(s)**

DNS (TCP 53)
DNS (UDP 53, 5353)
FTP (TCP 21)
FailedConnection (TCP 80, 5000, 34050, 42299, 45300, 45966, 48605, 50000, 51229, 52230, 56117)
HTTP (TCP 80)
Kerberos (TCP 88)
LDAP (TCP 389, 3268)
LDAP (UDP 389)
NFS (TCP 920)
NFS (UDP 944)
NTP (UDP 123)
NoData (TCP 35387, 43010, 446460, 47486)
NotAKnownOne (TCP 22, 389, 464, 3268, 9999, 33569, 42998, 47647, 52730, 53282, 55912, 60779, 60917)
NotAKnownOne (UDP 698, 861, 910, 918, 928, 9999, 44444, 44445, 44446)
SMB (TCP 139)
SMB (UDP 138)
SSH (TCP 22)
SSL (TCP 443)
Syslog (UDP 514)

**Server protocol(s)**

HTTP (TCP 1311)
NotAKnownOne (TCP 24793, 34119, 54181)
NotAKnownOne (TCP 5000, 50000)
NotAKnownOne (UDP 33443, 33444, 33445, 33446, 33447, 33448, 33449, 33450, 33451, 59798)
SunRPC (TCP 111, 2049)
SunRPC (UDP 111)

**Alert Details**

ID and name	lan_cp_pnw - Application protocol not whitelisted
Description	Application protocol not whitelisted: the application protocol used in the communication is not whitelisted for this host combination
Triggering rule/default action	alert

**Monitored networks**

Name	Address	VLAN IDs
RoboticsFieldBusLA	192.168.1.0/24	any
RoboticsControlLAN	192.168.0.0/24	any

864

Nr. of agrg. details	Event type ID	Event severity	L7 Protocol	Source IP	Destination IP	Sensor	First seen	Last seen
3	authentication_fail	Info	HTTP	192.168.0.20 (polaris)	192.168.1.101 (beaglebone-2.local)	Local (id=1)	Dec 11, 2017 13:07:00	Dec 11, 2017 13:07:00

865

### 866 A.3.9. Unauthorized ICS Device Firmware Update

867 Many ICS devices provide services to remotely update firmware over the network. These  
 868 network services can also provide a mechanism for attackers to replace valid firmware with  
 869 malicious firmware if the device is not protected.

870 This anomaly was executed on the PCS. The Allen-Bradley PLC implemented in the PCS  
 871 contains an Ethernet module (1756-EN2T) that allows its firmware to be upgraded and  
 872 downgraded over Ethernet/IP. The firmware was upgraded or downgraded using the  
 873 ControlFLASH firmware upgrade tool.

874

<input type="checkbox"/>	Dec 11, 2017 16:12:03	ETHIP controller reset co...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:12:03	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:12:01	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:12:01	Message type not whitelis...	Local	Comm...	8 - TCP co...	Not analyzed	<span style="color: yellow;">██████</span> M	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	Exit
<input type="checkbox"/>	Dec 11, 2017 16:12:01	Message type not whitelis...	Local	Comm...	8 - TCP co...	Not analyzed	<span style="color: yellow;">██████</span> M	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	Exit
<input type="checkbox"/>	Dec 11, 2017 16:12:00	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:12:00	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:12:00	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:12:00	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: yellow;">██████</span> M	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:11:28	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-
<input type="checkbox"/>	Dec 11, 2017 16:11:28	ETHIP firmware update c...	Local	Indust...	-	Not analyzed	<span style="color: red;">██████</span> H	172.16.3.10 (fgs-4...	172.16.2.102 (plc_...	44818 (TCP)	ETHIP	-

875

### A.3.10. Unauthorized HMI Logic Modification

Many ICS devices provide services to remotely update control logic over the network. These network services can also provide a mechanism for attackers to replace valid control logic with malicious logic if the device is not protected. This is especially important for HMIs, as they are typically used by operators to monitor and manipulate the manufacturing process in a safe and controlled manner.

882 This anomaly was executed on the CRS. The database implemented on the CRS Red Lion  
 883 HMI (Model G310) was modified and uploaded to the HMI by using the Red Lion Crimson  
 884 3.0 software. The Modbus TCP registers in the modified database differed slightly from  
 885 those in the original database.

886

n. of agg. details	Event name	Severity	Event-specific info	Protocol	Source IPs	Destination IPs	Destination Sensor - Engine - Profile ports	Min value	Max value	First event	Last event
15	Numeric field value outside whitelisted enumeration	Medium	Upstream/read_input_registers/star...	IP/TCP/MODBU...	192.168.0.98 (hmlan.lab)	192.168.0.30 (pic-roboticslan.lab)	502	1	Local - Protocol net...	32771	32771 Dec 12, 2017 Dec 12, 2017
15	Length field value outside whitelisted range	Medium	Upstream/read_discrete_inputs/qua...	IP/TCP/MODBU...	192.168.0.98 (hmlan.lab)	192.168.1.104 (station4lan.lab)	502	1	Local - Protocol net...	2	2 Dec 12, 2017 Dec 12, 2017
15	Numeric field value outside whitelisted enumeration	Medium	Upstream/read_discrete_inputs/sta...	IP/TCP/MODBU...	192.168.0.98 (hmlan.lab)	192.168.1.104 (station4lan.lab)	502	1	Local - Protocol net...	4	4 Dec 12, 2017 Dec 12, 2017
1	Numeric field value outside whitelisted enumeration	Medium	Upstream/read_holding_registers/sta...	IP/TCP/MODBU...	192.168.0.98 (hmlan.lab)	192.168.0.30 (pic-roboticslan.lab)	502	1	Local - Protocol net...	0	0 Dec 12, 2017 Dec 12, 2017
1	Source host not whitelisted	Medium		IP/TCP/NotAKn...	192.168.0.147 (knuckles.local)	192.168.0.98 (hmlan.lab)	789	1	Local - Communica...		Dec 12, 2017 Dec 12, 2017
1	Message type not whitelisted	Medium	Read Holding Registers Exception (1...	IP/TCP/MODBU...	192.168.0.98 (hmlan.lab)	192.168.0.30 (pic-roboticslan.lab)	502	1	Local - Communica...		Dec 12, 2017 Dec 12, 2017

887

### 888 A.3.11. ICS Device Receives Diagnostic Modbus TCP Function Codes

889 Certain ICS network protocols enable diagnostic access to ICS devices. While this type of  
 890 functionality enables remote maintenance and diagnostics to authorized personnel, it may  
 891 also be leveraged by aggressors to compromise ICS devices.

892 This anomaly was executed on the CRS. Python [14] was used to create a Modbus TCP  
 893 message with the diagnostic function code value of 43 (0x2B), known as encapsulated  
 894 interface transfer. The message was generated by the cybersecurity virtual machine  
 895 (CybersecVM) and was transmitted to the PLC Modbus server.

The screenshot shows the SilentDefense™ software interface. The top navigation bar includes tabs for Dashboard, Network, Events, Sensors, Settings, and Help. The main area is divided into several sections:

- Alert details:** Shows an alert with ID 10681, timestamp Dec 11, 2017 13:40:27, and a Local sensor. The detection engine is Protocol fields (DPBI). Profile is 10 - MB-to-0.30. Severity is Medium (yellow). Source MAC is 00:15:5D:04:5B:2B (Microsoft). Destination MAC is 00:01:05:17:DB:08 (Beckhoff). Source IP is 192.168.0.10. Destination IP is 192.168.0.30 (plc-robotics.lan.lab). Source port is 56346. Destination port is 502. L2 proto is Ethernet. L3 proto is IP. L4 proto is TCP. L7 proto is MODBUSTCP. TCP stream opened in hot start mode is false. Status is Not analyzed. Labels include uid=1. User notes are present.
- Source host info:** Details about the source host, including IP address (192.168.0.10), MAC addresses (00:15:5D:04:5B:2B (Microsoft) 94:8B:C5:0E:E1:9F (Ruggedcom)), Role (Master), Client protocol(s) (DNS (UDP 5353), FailedConnection (TCP 20, 21, 22, 443, 1020, 1021, 1022, 1023, 1024), HTTP (TCP 80, 5120), MODBUSTCP (TCP 502), SSDP (UDP 1900)), Server protocol(s) (SSH (TCP 22)), Purdue level (2 - Supervisory control), Criticality (H), Known vulnerabilities (0), Related alerts (57 (Show)), First seen (Dec 4, 2017 04:40:29), and Last seen (Dec 11, 2017 13:40:28).
- Destination host info:** Details about the destination host, including IP address (192.168.0.30), MAC addresses (00:01:05:17:DB:08 (Beckhoff) 94:8B:C5:0E:E1:9F (Ruggedcom)), Role (PLC), Other roles (Master, Slave, File server, Web server), Vendor/model (Beckhoff), Client protocol(s) (MODBUSTCP (TCP 502), NTP (UDP 123), SSDP (UDP 1900)), and Server protocol(s) (FTP (TCP 21), FTPDATA (TCP 20), TFTP (Dynamic)).
- Alert details (continued):** Shows details from parsed request/response, including ID and name (dpbi\_uv\_num\_set - Numeric field value outside whitelisted enumeration), Description (Unusual numeric field value: the value of a numeric field is not in the enumeration (set) of values allowed by the field model), Direction (Upstream), Field path (/upstream/header/fc), Field value (43 (0x2B)), and Field model ([2, 6], 15) - samples: 33.572.816.
- Details from parsed request/response:** Shows another set of details, including ID and name (dpbi\_nf\_frn - Field not whitelisted), Description (Field not whitelisted: an application protocol field used in the communication is not allowed by the protocol model), Direction (Upstream), Field path (/upstream/encapsulated\_interface\_transp ort), and Field value (Downstream).
- Events:** A table listing events with columns: Timestamp, Event name(s), Sensor, Engine, Profile, Status, Severity, Source IP, Destination IP, Dest. Port, and L7 Proto. The table contains two entries:

Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source IP	Destination IP	Dest. Port	L7 Proto
Dec 11, 2017 13:40:28	Communication patter...	Local	Corn...	8 - TCP c...	Not analyzed	■■■■ M	192.168.0.10	192.168.0.30 (p...	502 (TCP)	MODBUSTCP
Dec 11, 2017 13:40:27	Numeric field value ou...	Local	Prot...	10 - MB-t...	Not analyzed	■■■■ M	192.168.0.10	192.168.0.30 (p...	502 (TCP)	MODBUSTCP

896

897

### 898 A.3.12. ICS Device Receives Undefined Modbus TCP Function Codes

899 Communications that do not conform to the defined specifications of the industrial protocol  
 900 may cause an ICS device to act in an undefined or unsafe manner. Depending on the  
 901 manufacturing process and the ICS device, the nonconforming communications may or may  
 902 not be impactful, but investigation into the cause is warranted.

903 This anomaly was executed on the CRS. Python [14] was used to create a Modbus TCP  
 904 message with the undefined function code value of 49 (0x31). The message was generated  
 905 by the CybersecVM and was transmitted to the PLC Modbus server.

The screenshot shows the SilentDefense™ web application interface. The top navigation bar includes links for Dashboard, Network, Events, Sensors, Settings, and timzim. Below the navigation is a toolbar with Back, Edit, Delete, Trim, Show (with a dropdown), Download pcap, and Help.

**Alert details**

Alert ID	10673
Timestamp	Dec 11, 2017 13:37:02
Sensor name	Local
Detection engine	Protocol fields (DPI)
Profile	10 - MB-to-0.30
Severity	Medium
Source MAC	00:15:5D:04:5B:2B (Microsoft)
Destination MAC	00:01:05:17:DB:08 (Beckhoff)
Source IP	192.168.0.10
Destination IP	192.168.0.30 (pic-robotics.lan.lab)
Source port	56342
Destination port	502
L2 proto	Ethernet
L3 proto	IP
L4 proto	TCP
L7 proto	MODBUSTCP
TCP stream opened in hot start mode	false
Status	Not analyzed
Labels	uid=1
User notes	

**Monitored networks**

Name	Address	VLAN IDs
RoboticsControlLAN	192.168.0.24	any

**Source host info**

IP address	192.168.0.10 [Private IP]
MAC addresses	00:15:5D:04:5B:2B (Microsoft) 94:B8:C5:0E:E1:9F (Ruggedco)
Role	Master
Client protocol(s)	DNS (UDP 5353) FailedConnection (TCP 20, 21, 22, 443, 1020, 1021, 1022, 1023, 1024) HTTP (TCP 80, 5120) MODBUSTCP (TCP 502) SSDP (UDP 1900)
Server protocol(s)	SSH (TCP 22)
Purdue level	2 - Supervisory control
Criticality	H
Known vulnerabilities	0
Related alerts	55 [Show]
First seen	Dec 4, 2017 04:40:29
Last seen	Dec 11, 2017 13:37:03

**Destination host info**

IP address	192.168.0.30 [Private IP]
MAC addresses	00:01:05:17:DB:08 (Beckhoff) 94:B8:C5:0E:E1:9F (Ruggedco)
Role	PLC
Other roles	Master, Slave, File server, Web server
Vendor/model	Beckhoff
Client protocol(s)	MODBUSTCP (TCP 502) NTP (UDP 123) SSDP (UDP 1900)
Server protocol(s)	FTP (TCP 21) FTPS (TCP 993, data channel)

**Alert details**

Details from parsed request/response: 0 ▾

Show parsed request/response	Show
------------------------------	------

ID and name: `dpbl_uv_nun_set` - Numeric field value outside whitelisted enumeration

Description: Unusual numeric field value; the value of a numeric field is not in the enumeration (set) of values allowed by the field model

Direction: Upstream

Field path: `/upstream/header/fc`

Field value: 49 (0x31)

Field model:  $\{[2..6], 15\}$  - samples: 33,572,816

ID and name: `dpbl_nf_frw` - Field not whitelisted

Description: Field not whitelisted; an application protocol field used in the communication is not allowed by the protocol model

Direction: Upstream

Field path: `/upstream/other`

**Alert data**

Upstream data: 8 B    ASCII    Hexadecimal    Mixed

0000 00 00 00 00 00 02 01 31 ..

906

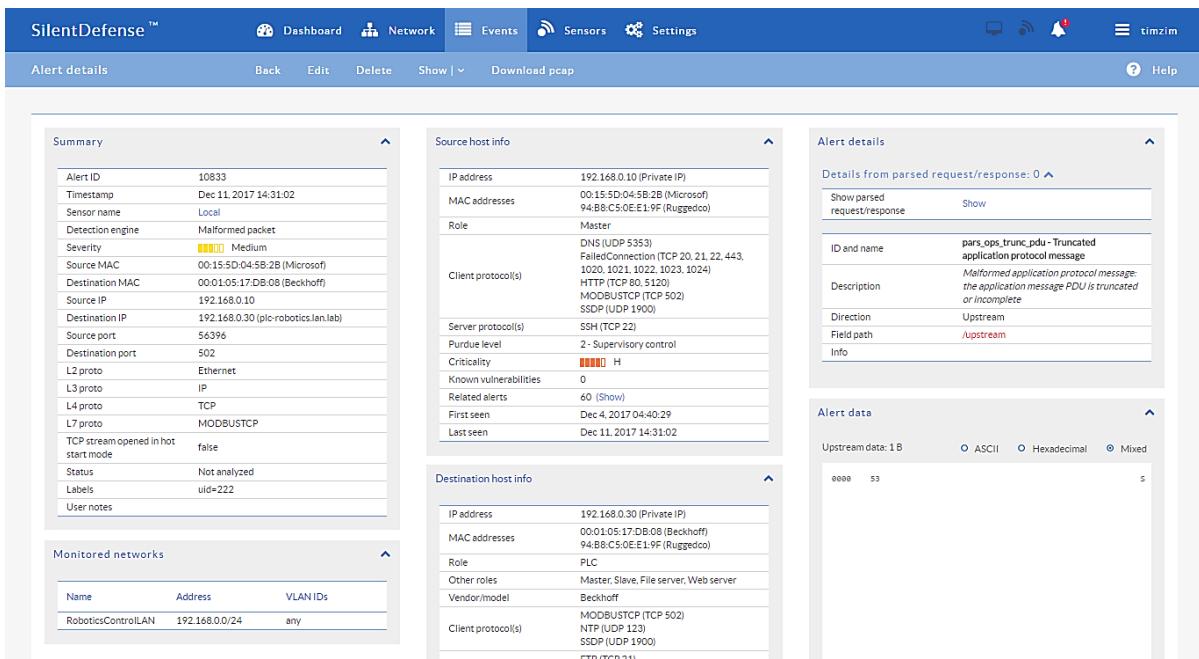
Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source IP	Destination IP	Dest. Port	L7 Proto
Dec 11, 2017 13:37:02	Communication patter...	Local	Com...	8 - TCP c...	Not analyzed	INFO M	192.168.0.10	192.168.0.30 (p...	502 (TCP)	MODBUSTCP
Dec 11, 2017 13:37:02	Numeric field value ou...	Local	Prot...	10 - MB-t...	Not analyzed	INFO M	192.168.0.10	192.168.0.30 (p...	502 (TCP)	MODBUSTCP

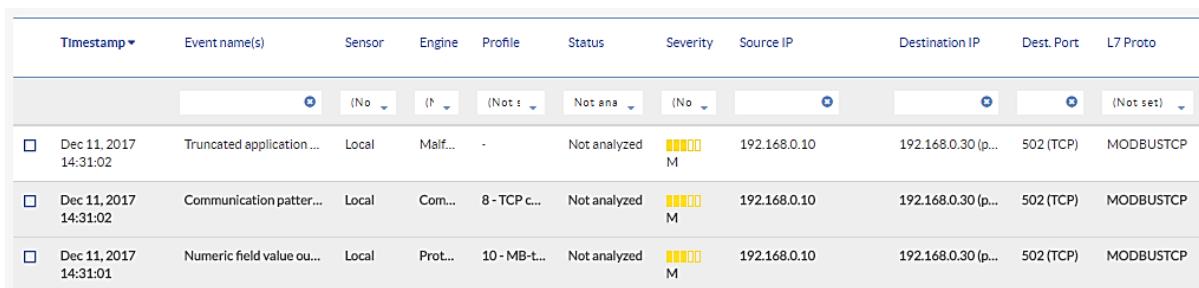
907

### A.3.13. ICS Device Receives Malformed Modbus TCP Traffic

909 Communications that do not conform to the defined specifications of the industrial protocol  
910 may cause an ICS device to act in an undefined or unsafe manner. Depending on the  
911 manufacturing process and the ICS device, the nonconforming communications may or may  
912 not be impactful, but investigation into the cause is warranted.

913 This anomaly was executed on the CRS. Python [14] was used to create a malformed  
914 Modbus TCP message. The message was generated by the CybersecVM and was transmitted  
915 to the PLC Modbus server.

916 

917 

### 918 A.3.14. Illegal Memory Addresses of ICS Device Are Accessed

- 919 Some industrial protocols (like Modbus) require relative addressing to access ICS device  
 920 registers. Attackers may attempt to modify illegal memory locations of ICS devices by using  
 921 these types of industrial protocols or may attempt to cause the ICS device to act in an  
 922 undefined or unsafe manner by modifying data located in a protected memory location.  
 923 This anomaly was executed on the CRS. The HMI database was modified to access an illegal  
 924 register on the PLC Modbus TCP server when the anomaly was activated. The valid Modbus  
 925 address range for the PLC registers is 0x8000 to 0x80FF.

Alert details

Back Edit Delete Trim Show | Download pcap Help

**Summary**

Alert ID	10883
Timestamp	Dec 11 2017 14:34:58
Sensor name	Local
Detection engine	Protocol fields (DPBI)
Profile	10 - MB-to-0.30
Severity	Medium
Source MAC	00:05:E4:03:7C:3B (RedLionC)
Destination MAC	00:01:05:17:DB:08 (Beckhoff)
Source IP	192.168.0.98 (hmlan.lab)
Destination IP	192.168.0.30 (plc-roboticslan.lab)
Source port	37368
Destination port	502
L2 proto	Ethernet
L3 proto	IP
L4 proto	TCP
L7 proto	MODBUSTCP
TCP stream opened in hot start mode	false
Status	Not analyzed
Labels	uid=1
User notes	

**Monitored networks**

Name	Address	VLAN IDs
RoboticsControlLAN	192.168.0.0/24	any

**Source host info**

IP address	192.168.0.98 (Private IP)
MAC addresses	00:05:E4:03:7C:3B (RedLionC) 94:88:C5:0E:E1:9F (Ruggedcom)
Role	Master
Other roles	File server, Web server
Client protocol(s)	MODBUSTCP (TCP 502)
Server protocol(s)	FTP (TCP 21) HTTP (TCP 80) NoData (TCP 35387, 43010, 45011, 46460, 47486)
Purdue level	2 - Supervisory control
Criticality	Medium
Known vulnerabilities	0
Related alerts	309 (Show)
First seen	Dec 4, 2017 04:28:10
Last seen	Dec 11, 2017 14:35:24

**Destination host info**

IP address	192.168.0.30 (Private IP)
MAC addresses	00:01:05:17:DB:08 (Beckhoff) 94:88:C5:0E:E1:9F (Ruggedcom)
Role	PLC
Other roles	Master, Slave, File server, Web server
Vendor/model	Beckhoff
Client protocol(s)	MODBUSTCP (TCP 502) NTP (UDP 123) SSDP (UDP 1900)
Server protocol(s)	FTP (TCP 21) FTFPDATA (TCP dynamic) HTTP (TCP 80, 5120)

**Alert details**

**Details from parsed request/response: 0**

Show parsed request/response Show

ID and name: dpbl\_uv\_num\_set - Numeric field value outside whitelisted enumeration  
Unusual numeric field value: the value of a numeric field is not in the enumeration (set of values allowed by the field model)

Description: Unusual numeric field value: the value of a numeric field is not in the enumeration (set of values allowed by the field model)

Direction: Upstream

Field path: /upstream/write\_single\_register/register\_address

Field value: 399 (0x18F)

Field model: {32778, 32782}; samples: 8

**Details from parsed request/response: 1**

Show parsed request/response Show

ID and name: dpbl\_nf\_fnw - Field not whitelisted  
Field not whitelisted; an application protocol field used in the communication is not allowed for the communication model

Description: Field not whitelisted; an application protocol field used in the communication is not allowed for the communication model

926

Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source IP	Destination IP	Dest. Port	L7 Proto
Dec 11, 2017 14:34:58	Message type not whitelisted	Local	Com...	8 - TCP c...	Not analyzed	Medium	192.168.0.98	192.168.0.30 (p...	502 (TCP)	MODBUSTCP
Dec 11, 2017 14:34:58	Numeric field value outside whitelisted enumeration	Local	Prot...	10 - MB-t...	Not analyzed	Medium	192.168.0.98	192.168.0.30 (p...	502 (TCP)	MODBUSTCP

927

### A.3.15. ICS Device Scanning Is Performed on the Network

- During the reconnaissance phase, an attacker may attempt to locate vulnerable devices in an ICS network and will likely probe for ICS-specific services (e.g., Modbus TCP). Once a vulnerable service is discovered, an attacker may attempt to exploit that service.
- This anomaly was executed on the CRS. The software Nmap [16] was used to generate the Modbus device scan by using the script `modbus-discover` [18]. The attack was directed at two ICS devices: the PLC and Machining Station 4.

SilentDefense™

Dashboard Network Events Sensors Settings timzim

Alert details Back Edit Delete Trim Show | v Download pcap Help

**Summary**

Alert ID	10909
Timestamp	Dec 11, 2017 14:38:08
Sensor name	Local
Detection engine	Protocol fields (DPBI)
Profile	10 - MB-to-0.30
Severity	Medium
Source MAC	00:15:5D:04:5B:2B (Microsoft)
Destination MAC	00:01:05:17:DB:08 (Beckhoff)
Source IP	192.168.0.10
Destination IP	192.168.0.30 (pic-robotics.lan.lab)
Source port	56410
Destination port	502
L2 proto	Ethernet
L3 proto	IP
L4 proto	TCP
L7 proto	MODBUS/TCP
TCP stream opened in hot start mode	false
Status	Not analyzed
Labels	uid=2
User notes	

**Monitored networks**

Name	Address	VLAN IDs
RoboticsControlLAN	192.168.0.0/24	any

**Source host info**

IP address	192.168.0.10 (Private IP)
MAC addresses	00:15:5D:04:5B:2B (Microsoft) 94:88:C5:0E:E1:9F (Ruggedbox)
Role	Master
Client protocol(s)	DNS (UDP 53/53) File download (TCP 20, 21, 22, 443, 1023, 1024, 1025, 1026, 1027, 1028) HTTP (TCP 80, 5120) MODBUS/TCP (TCP 502) SSDP (UDP 1900)
Server protocol(s)	SSH (TCP 22)
Purdue level	2 - Supervisory control
Criticality	H
Known vulnerabilities	0
Related alerts	66 (Show)
First seen	Dec 4, 2017 04:40:29
Last seen	Dec 11, 2017 14:38:17

**Alert details**

Details from parsed request/response: 0 ▾

Show parsed request/response	Show
ID and name	dpbi_uv_num_set - Numeric field value outside whitelisted enumeration
Description	Unusual numeric field value: the value of a numeric field is not in the enumeration (set) of values allowed by the field model
Direction	Upstream
Field path	/upstream/header/rfc
Field value	17 (0x11)
Field model	[[2..6], 15] - samples: 33.572.816
ID and name	dpbi_uv_num_set - Numeric field value outside whitelisted enumeration
Description	Unusual numeric field value: the value of a numeric field is not in the enumeration (set) of values allowed by the field model
Direction	Upstream
Field path	/upstream/header/vid
Field value	2 (0x02)
Field model	[[0..1]] - samples: 33.572.816
ID and name	dpbi_nf_frw - Field not whitelisted
Description	Field not whitelisted: an application protocol field used in the communication is not allowed by the protocol model
Direction	Upstream
Field path	/upstream/report_slave

935

n. of agg. details	Event name	Severity	Event-specific info	Protocol	Source IPs	Destination IPs	Destination Sensor - Engine - Profile ports	Min value	Max value	First event	Last event
(Not set)											
93 14	Communication pattern not whitelisted	Medium		IP/TCP/MODBU...	192.168.0.10	3 destination IPs	502	1 - Local - Communic...		Dec 11, 2017 Dec 11, 2017	
93 10	Numeric field value outside whitelisted enumeration	Medium	/upstream/header/rfc	IP/TCP/MODBU...	192.168.0.10	192.168.0.30 (pic-robotics.lan.lab)	502	1 - Local - Protocolf...	17 17	Dec 11, 2017 Dec 11, 2017	
93 10	Field not whitelisted	Medium	/upstream/report_slave	IP/TCP/MODBU...	192.168.0.10	192.168.0.30 (pic-robotics.lan.lab)	502	1 - Local - Protocolf...		Dec 11, 2017 Dec 11, 2017	
93 9	Numeric field value outside whitelisted enumeration	Medium	/upstream/header/vid	IP/TCP/MODBU...	192.168.0.10	192.168.0.30 (pic-robotics.lan.lab)	502	1 - Local - Protocolf...	2 10	Dec 11, 2017 Dec 11, 2017	
93 2	Length field value outside whitelisted range	Medium	/upstream/header/len	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...	2 5	Dec 11, 2017 Dec 11, 2017	
93 2	Numeric field value outside whitelisted enumeration	Medium	/downstream/header/fc	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...	43 145	Dec 11, 2017 Dec 11, 2017	
93 2	Numeric field value outside whitelisted enumeration	Medium	/upstream/header/fc	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...	17 43	Dec 11, 2017 Dec 11, 2017	
93 1	Field not whitelisted	Medium	/downstream/encapsulated_interface...	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...		Dec 11, 2017 Dec 11, 2017	
93 1	Field not whitelisted	Medium	/downstream/report_slave_exception	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...		Dec 11, 2017 Dec 11, 2017	
93 1	Field not whitelisted	Medium	/upstream/encapsulated_interface...	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...		Dec 11, 2017 Dec 11, 2017	
93 1	Field not whitelisted	Medium	/upstream/report_slave	IP/TCP/MODBU...	192.168.0.10	192.168.1.104 (station4.lan.lab)	502	1 - Local - Protocolf...		Dec 11, 2017 Dec 11, 2017	

936

937 **Appendix B. Secure-NOK SNOK Supplemental Information**

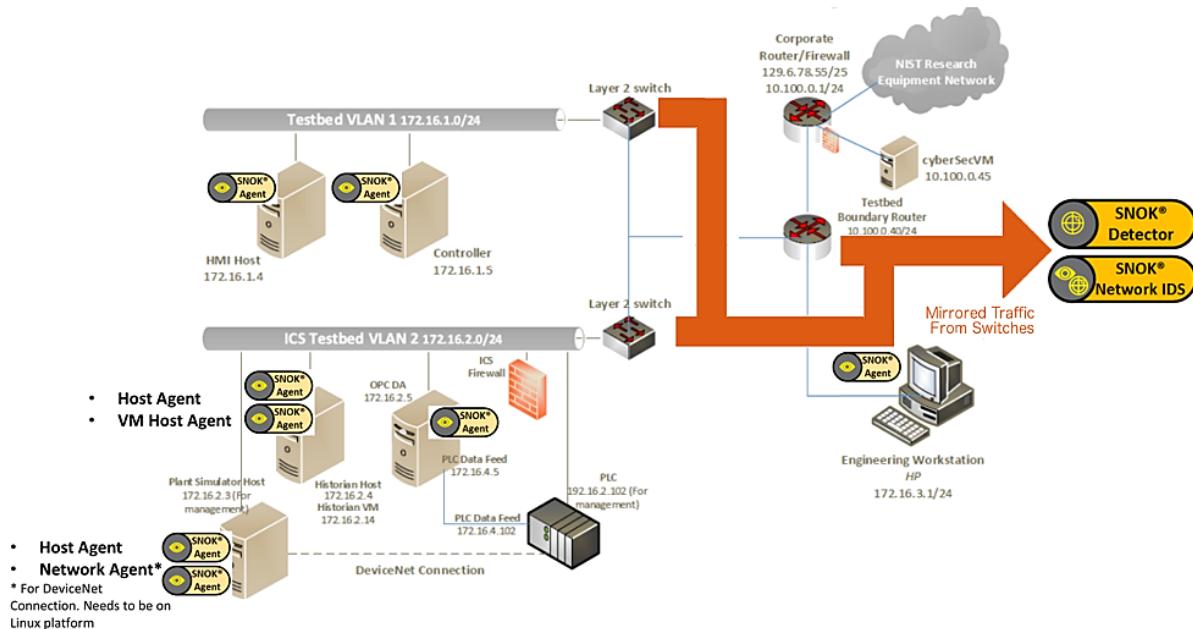
938 Secure-NOK SNOK is a cybersecurity monitoring and detection system tailored for  
939 industrial networks and control systems. In the installation, the SNOK network intrusion  
940 detection system (IDS) comes preinstalled on an appliance that is integrated into the asset  
941 owner's environment.

942 **B.1. Build Architecture**

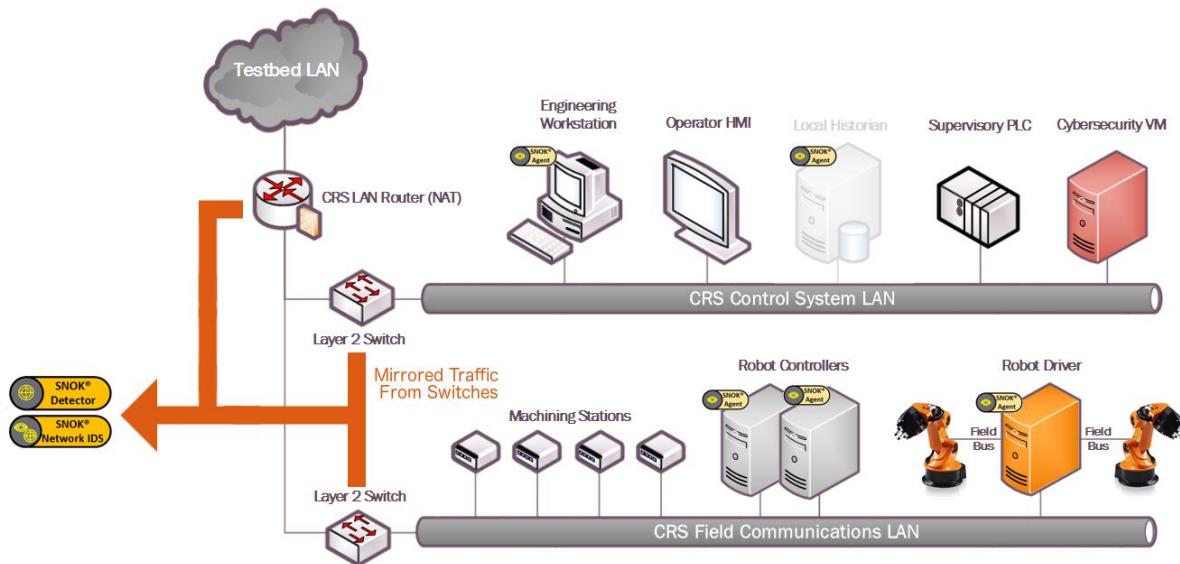
943 Two SNOK dedicated appliances were physically installed in the measurement rack of the  
944 Cybersecurity for Smart Manufacturing Systems (CSMS) environment. One appliance was  
945 dedicated to the process control system (PCS), and the other appliance was dedicated to the  
946 collaborative robotic system (CRS). Three existing Switch Port Analyzer (SPAN) ports from  
947 each system (PCS and CRS) were connected to a VERSAstream packet broker (VS-1208BT-  
948 S) to aggregate the mirrored traffic from the PCS and the CRS into two respective streams,  
949 for a total of six SPAN ports. The appliance connections within the PCS and CRS networks  
950 are shown in Figure B-1 and Figure B-2, respectively.

951 The PCS appliance network was connected to the demilitarized zone (DMZ) network located  
952 in the test bed's measurement rack, to isolate the appliance's network traffic from the rest of  
953 the network traffic. The engineering laptop was used to interface with the SNOK graphical  
954 user interface (GUI) via physical connections to the DMZ. The CRS appliance network was  
955 connected to the industrial control system (ICS) local area network (LAN), and the SNOK  
956 GUI was accessed via the engineering workstation. More information regarding the specific  
957 configuration of the test-bed network can be found in Section 3.

958 **Figure B-1 SPAN Port Connections to the SNOK Appliance in the PCS (Including the Hosts  
959 with SNOK Agents)**



961     **Figure B-2 SPAN Port Connections to the SNOK Appliance in the CRS (Including the Hosts**  
962     **with SNOK Agents)**



963

## 964     **B.2. Installation and Configuration**

965     Physical hardware appliances and software were provided by Secure-NOK for this  
966     demonstration. After the hardware appliances were received, they were installed into the  
967     CSMS test bed. Soon after the initial installation, engineers from Secure-NOK arrived on site  
968     to complete the installation and configuration of the tool. The following subsections describe  
969     the steps taken to install and configure the appliances.

### 970     **B.2.1. Hardware**

971     The hardware used included two Siemens SIMATIC industrial personal computers (IPCs)  
972     executing the SNOK services: a SIMATIC IPC227E for the PCS and a SIMATIC IPC427E  
973     for the CRS. A VERSAstream packet broker (VS-1208BT-S) was used to aggregate the  
974     mirrored traffic from the PCS and the CRS into two respective streams, one for each IPC.

### 975     **B.2.2. Windows XP / Windows 7 / Windows Server 2012 Installation**

976     The steps in this section describe the installation of SNOK Agents on endpoints with  
977     Microsoft Windows operating systems (OSs).

- 978       1. Launch *SNOKAgentSetup.exe* from the Windows Agent folder in the installation  
979        pack.
- 980       2. Click **Next>**.
- 981       3. Select both components, and then click **Next>**.
- 982       4. Input the username and password for administrative privileges, and then click **Install**.

- 983       5. Modify the configuration file located at <installation directory>|SNOK-  
984       agent\bin\snokeconfig.txt to include the following information:  
985           a. **idAgent**: a unique identifier (ID) that will not be used by any other agent that  
986           reports to the same SNOK Detector  
987           b. **detectorIP**: the Internet Protocol (IP) address of the SNOK Detector to which  
988           the agent will report  
989           c. **licenseKey**: the license key provided for the SNOK Detector

990       **B.2.2.1. Start SNOK Agent Manually**

991       If the installation did not include selecting **Automatically start agent**, then follow the steps  
992       below to manually start the agent:

- 993       1. Open the command prompt.  
994       2. Change the directory to <installation directory>|bin\ by using the following  
995           command:

```
996       > cd C:\SNOK\bin\
```

- 997       3. Run the agent by using the following command and then pressing the **Enter** key:

```
998       > SNOKEAgent.exe
```

999       **B.2.2.2. Stop SNOK Agent Manually**

- 1000       1. Open the **Task Manager**.  
1001       2. Open the **Processes** tab.  
1002       3. Select the process name **SNOKEAgent.exe**.  
1003       4. Click the **End Task** button.

1004       **B.2.3. Ubuntu 12 / Ubuntu 14 Installation**

- 1005       1. Copy the file *snokeagent\_<version>.deb* into the */home* directory of the IPC.  
1006       2. Add the Debian Wheezy universe to the apt sources file by using the following  
1007           command:

```
1008       > sudo echo "deb http://httpredir.debian.org/debian wheezy  
1009           main" >> /etc/apt/sources.list
```

- 1010       3. Install the libpcap-dev package by using the following command:

```
1011       > sudo apt-get install libpcap-dev
```

- 1012        4. Install the SNOK Agent from the Debian software package file by using the  
1013            following command:
- 1014            > sudo dpkg -I ~/snoknetmonagent\_<version>.deb
- 1015        5. Modify the configuration file *snok-netmonconfig.txt* located in the directory  
1016            */etc/default/* to include the following information:
- 1017            a. **idAgent**: a unique ID that will not be used by any other agent that reports to  
1018              the same SNOK Detector
- 1019            b. **detectorIP**: the IP address of the SNOK Detector to which the agent will  
1020              report
- 1021            c. **licenseKey**: the license key provided for the SNOK Detector

#### 1022        **B.2.4. SNOK Detector Configuration**

1023        The SNOK Detector comes installed as part of a preconfigured appliance, requiring final  
1024            configuration before integration into the asset owner's environment. The following  
1025            configuration must be completed on the appliance before installation:

- 1026        1. Obtain a license key from Secure-NOK. The media access control (MAC) address of  
1027            the network interface is needed to generate the license. On the appliance, execute the  
1028            following command to obtain the address, which will be the hexadecimal number  
1029            after `HWaddr`, in the format of `xx:xx:xx:xx:xx:xx`:

1030            > sudo ifconfig eth0

- 1031        2. Copy the license key file *snoklicense.key* to the directory */home/snok/*.  
1032        3. Start the configuration software by using the following command:

1033            > sudo /usr/share/snok/snok-config.sh

- 1034        4. Ensure that *1 (VMs Installation) SNOK Detector with local Visualizer* is highlighted,  
1035            and then press the **Enter** key.
- 1036        5. On the Database VM IP page, enter the IP address of the preconfigured appliance,  
1037            and then press the **Enter** key.
- 1038        6. On the Detector mode page, ensure the messages received are not forwarded  
1039            (isolated) and is selected, and then press the **Enter** key.
- 1040        7. On the Date-Time Synchronization page, select **1 Enter IP for Simple Network**  
1041            **Time Protocol Server** (Network Time Protocol [NTP] / Simple Network Time  
1042            Protocol [SNTP] server available), and then press the **Enter** key.
- 1043        8. On the NTP/SNTP IP page, type the IP address of the NTP server, and then press the  
1044            **Enter** key. The lab NTP server (10.100.0.15) was used for the build environment.

1045        9. On the External Event Reporting page, select any reporting methods, and then press  
1046        the **Enter** key. The build configuration did not require any external reporting  
1047        (e.g., syslog, email), so the *option 3 Go to next step* was selected.

1048        10. When prompted, enter the database password to enable the automated configuration.

1049        11. Start the snok-box service by using the following command:

```
1050 > sudo service snok-box start
```

1051        12. Start the snok-dumper service by using the following command:

```
1052 > sudo service snok-dumper start
```

### 1053        **B.3. Anomaly Scenarios**

1054        The agent-based anomaly detection method was demonstrated for the scenarios detailed in  
1055        the following subsections. Each scenario includes a description of the anomaly, a detailed  
1056        description of how each demonstration event was conducted in the CSMS environment, and  
1057        the observed results.

1058        For the sake of brevity, only a subset of the alerts observed during the demonstration is  
1059        shown. However, each anomaly scenario includes a screenshot of the alerts summary  
1060        observed after the anomaly scenario had completed.

#### 1061        **B.3.1. Web Browser Is Used to Access the Internet**

1062        The detection of unauthorized internet traffic on ICS networks is important for mitigating  
1063        risk to the manufacturing system. Internet-accessible network connections introduce a  
1064        gateway for malware into the ICS network, as well as a gateway for sensitive manufacturing  
1065        system data to be exfiltrated out of the ICS network.

1066        This anomaly was executed on the CRS. A Hypertext Transfer Protocol (HTTP) server was  
1067        installed and configured on a server with an internally routed public IP address (129.6.1.2).  
1068        The Firefox web browser was used to connect to a web page, from the engineering  
1069        workstation to the internet-based HTTP server.

1070	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: firefox-esr					
1071	NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/16/2018 13:12:02	..	Unexpected new connection	A new IP address has been detected in the network	Source IP: 129.6.1.2 Destination IP: 192.168.0.20 Source MAC Address: 94:b8:c5:0e:e1:9f Destination MAC Address: f8:b1:56:ba:09:a8	
1072	129.6.1.2 94:b8:c5:0e:e1:9f	192.168.0.20 f8:b1:56:ba:09:a8	HTTP	02/16/2018 13:11:59	02/16/2018 13:13:01	0.15	0.98

1073    **B.3.2. Data Exfiltration to the Internet via HTTP**

1074    Attacks against ICS, with the goal of information gathering, must (at some point) attempt to  
1075    exfiltrate sensitive or proprietary data from the ICS network, potentially utilizing the internet  
1076    as a transport mechanism. Monitoring for ICS devices communicating to other devices over  
1077    the internet can help detect data exfiltration events, especially if the affected device does not  
1078    normally communicate over the internet.

1079    This anomaly was executed on the CRS. An HTTP server and the PHP (Hypertext  
1080    Preprocessor) server-side scripting language [19] were installed and configured on a server  
1081    with an internally routed public IP address (129.6.1.2). A PHP web page was created to  
1082    enable file uploads over HTTP. The web page was accessed by the Firefox web browser on  
1083    the engineering workstation, and the sensitive file *ControlsSchematic.dwg*, an AutoCAD  
1084    drawing file, was selected and uploaded to the server.

NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/16/2018 13:07:52	Unexpected new connection	A new IP address has been detected in the network	Source IP: 129.6.1.2 Destination IP: 192.168.0.20 Source MAC Address: 94:b8:c5:0:e:e1:9f Destination MAC Address: f8:b1:56:ba:09:a8	Authorized by: admin Timestamp: 02/16/2018 13:12:00 Message:
---	---------------------	---------------------------	---	--	---

1085

NIST EL Collaborative Robots Sys All segments Engineering WS	02/16/2018 13:10:23	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: wget	<input type="button" value="Authorize"/>
---	---------------------	-------------------------	--	--

1086

Source IP Source MAC	Destination Destination MAC	Protocol Type	Start Timestamp	End Timestamp	Packets/second	kBits/second
192.168.0.20 f8:b1:56:ba:09:a8	129.6.1.2 94:b8:c5:0:e:e1:9f	HTTP	02/16/2018 13:23:27	02/16/2018 13:24:30	0.17	0.08

1087

1088    **B.3.3. European Institute for Computer Antivirus Research Virus Test File Is  
1089    Detected on Host**

1090    Computer viruses and malware are serious threats to the ICS. They can undermine the ICS  
1091    security, confidentiality, and stability, and can even sabotage the ICS. Providing the ability to  
1092    detect viruses and malware in the ICS network is important.

1093    This anomaly was executed on the PCS. Before the CyberX platform tool was installed, a  
1094    European Institute for Computer Antivirus Research (EICAR) test file was created and stored  
1095    on the engineering workstation.

Host	Timestamp	Type	Description
NIST EL Process Control All Segments Engineering WS	02/21/2018 12:47:00	Security Policy Violation	Security Policy Violation : Anti-Virus Event : Anti-Virus Disabled Network Segment Security Policy Violation

1096

1097    **B.3.4. Host Scanning Is Performed on the Network**

1098    During the reconnaissance phase, an attacker may attempt to locate vulnerable devices on an  
1099    ICS network. A host scan is one method to discover hosts or devices in the network. Once a  
1100    host or device is discovered and identified, an attacker may attempt to exploit the host or  
1101    device.

This anomaly was executed on the PCS. The software Nmap [16] was used to perform a host discovery scan of the ICS network on the subnet 172.16.2.0/24. The scan originated from the cybersecurity virtual machine (CybersecVM), logically located in the test-bed LAN.

1105

1106 **B.3.5. Port Scanning Is Performed on the Network**

1107 During the reconnaissance phase, an attacker may attempt to locate vulnerable services in an  
 1108 ICS network, likely probing for any open network ports to determine if a specific network  
 1109 service is available (e.g., Modbus). Once a vulnerable service is discovered, an attacker may  
 1110 attempt to exploit that service.

1111 This anomaly was executed on the CRS. The software Nmap [16] was used to perform a  
 1112 network scan for devices with the Modbus service enabled (Port 502). The scan originated  
 1113 from the CybersecVM, logically hosted on the historian located in the test-bed LAN.

NIST EL Collaborative Robots Sys All segments Historian	02/20/2018 13:43:42	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: nmap	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
--	---------------------	-------------------------	--	---

1114

NetMonAgent	Timestamp	Type	Description	Connection Details	Authorization
NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/20/2018 13:44:29	Unexpected new connection	A new IP address has been detected in the network	Source IP: 192.168.0.10 Destination IP: 192.168.0.30 Source MAC Address: 00:15:5d:02:0a:0e Destination MAC Address: 00:01:05:17:db:08	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/20/2018 13:44:29	Unexpected new connection	A new IP address has been detected in the network	Source IP: 192.168.0.10 Destination IP: 192.168.0.60 Source MAC Address: 00:15:5d:02:0a:0e Destination MAC Address: 00:30:de:00:c4:3c	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/20/2018 13:44:29	Unexpected new connection	A new IP address has been detected in the network	Source IP: 192.168.0.10 Destination IP: 192.168.1.104 Source MAC Address: 00:15:5d:02:0a:0e Destination MAC Address: 94:b8:c5:0e:e1:9f	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/20/2018 13:44:29	Unexpected new connection	A new IP address has been detected in the network	Source IP: 192.168.0.10 Destination IP: 192.168.1.104 Source MAC Address: 94:b8:c5:0e:e1:9f Destination MAC Address: b0:d5:cc:f4:26:ec	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>

1115

NIST EL Process Control All Segments PCS NetMon	02/21/2018 13:33:00	Unexpected new connection	A new IP address has been detected in the network	Source IP: 10.100.0.28 Destination IP: 172.16.1.5 Source MAC Address: e4:90:69:3b:c2:c4 Destination MAC Address: 0c:c4:7a:31:3e:d7	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
NIST EL Process Control All Segments PCS NetMon	02/21/2018 13:33:00	Unexpected new connection	A new IP address has been detected in the network	Source IP: 10.100.0.28 Destination IP: 172.16.1.4 Source MAC Address: e4:90:69:3b:c2:c4 Destination MAC Address: 0c:c4:7a:31:44:47	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
NIST EL Process Control All Segments PCS NetMon	02/21/2018 13:33:00	Unexpected new connection	A new IP address has been detected in the network	Source IP: 10.100.0.28 Destination IP: 172.16.1.4 Source MAC Address: 00:15:5d:02:0a:08 Destination MAC Address: e4:90:69:3b:c2:c1	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>
NIST EL Process Control All Segments PCS NetMon	02/21/2018 13:33:00	Unexpected new connection	A new IP address has been detected in the network	Source IP: 10.100.0.28 Destination IP: 172.16.1.5 Source MAC Address: 00:15:5d:02:0a:08 Destination MAC Address: e4:90:69:3b:c2:c1	<span style="background-color: red; color: white; border-radius: 5px; padding: 2px;">Authorize</span>

1116

Source IP Source MAC	Destination Destination MAC	Protocol Type	Start Timestamp	End Timestamp	Packets/second	kBits/second
192.168.0.10 00:15:5d:02:0a:0e	192.168.0.30 00:01:05:17:db:08	Modbus/TCP	02/20/2018 13:43:24	02/20/2018 13:44:27	0.49	0.00
192.168.0.10 00:15:5d:02:0a:0e	192.168.0.60 00:30:de:00:c4:3c	Modbus/TCP	02/20/2018 13:43:24	02/20/2018 13:44:27	0.15	0.00
192.168.0.10 00:15:5d:02:0a:0e	192.168.1.104 94:b8:c5:0e:e1:9f	Modbus/TCP	02/20/2018 13:43:24	02/20/2018 13:44:27	0.76	0.01
192.168.0.10 94:b8:c5:0e:e1:9f	192.168.1.104 b0:d5:cc:f4:26:ec	Modbus/TCP	02/20/2018 13:43:24	02/20/2018 13:44:27	0.38	0.00

1117

- 1118    **B.3.6. Unauthorized Installation of Software**
- 1119    Many Linux distributions provide an automated method to download and install packages.  
 1120    Often, these packages originate from third parties and may not be validated against the ICS  
 1121    environments. Attackers may install unvalidated, or even malicious, packages to the ICS. The  
 1122    ability to detect unauthorized downloads and unauthorized installations of software is  
 1123    important.
- 1124    This anomaly was executed on the CRS. The Advanced Package Tool (apt-get) was used to  
 1125    install a small package with minimal dependencies (md5deep). The installation was  
 1126    performed on the engineering workstation via the command line.

Host	Timestamp	Type	Description	Authorization
NIST EL Collaborative Robots Sys All segments Robotic Driver	02/20/2018 11:12:35	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: python	<a href="#">Authorize</a>
NIST EL Collaborative Robots Sys All segments Robotic Driver	02/20/2018 11:12:33	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: /bin/dbus-daemon	<a href="#">Authorize</a>
NIST EL Collaborative Robots Sys All segments Robotic Driver	02/20/2018 11:12:05	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: [dpkg]	<a href="#">Authorize</a>

1127

NetMonAgent	Timestamp	Type	Description	Connection Details	Authorization
NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/20/2018 11:13:12	Unexpected new connection	A new IP address has been detected in the network	Source IP: 192.168.1.5 Destination IP: 91.189.94.25 Source MAC Address: a0:ce:c8:1f:bd:99 Destination MAC Address: 94:b8:c5:0e:e1:9f	<a href="#">Authorize</a>
NIST EL Collaborative Robots Sys All segments NetworkAgent 1	02/20/2018 11:12:09	Unexpected new connection	A new IP address has been detected in the network	Source IP: 192.168.1.5 Destination IP: 91.189.91.23 Source MAC Address: a0:ce:c8:1f:bd:99 Destination MAC Address: 94:b8:c5:0e:e1:9f	<a href="#">Authorize</a>

1128

Source IP Source MAC	Destination Destination MAC	Protocol Type	Start Timestamp	End Timestamp	Packets/second	kBits/second
192.168.1.5 a0:ce:c8:1f:bd:99	91.189.94.25 94:b8:c5:0e:e1:9f	HTTP	02/20/2018 11:12:05	02/20/2018 11:13:08	0.03	0.00

1129

### 1130    **B.3.7. Unauthorized Programmable Logic Controller Firmware Update**

1131    Many ICS devices provide services to remotely update firmware over the network. These  
 1132    network services can also provide a mechanism for attackers to replace valid firmware with  
 1133    malicious firmware if the device is not protected.

1134    This anomaly was executed on the PCS. The Allen-Bradley programmable logic controller  
 1135    (PLC) implemented in the PCS contains an Ethernet module (1756-EN2T) that allows its  
 1136    firmware to be upgraded and downgraded over Ethernet/IP. The firmware was upgraded or  
 1137    downgraded using the ControlFLASH firmware upgrade tool.

Host	Timestamp	Type	Description	Authorization
NIST EL Collaborative Robots Sys All segments Robotic Driver	02/20/2018 11:12:35	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name: python	<button>Authorize</button>
NIST EL Collaborative Robots Sys All segments Robotic Driver	02/20/2018 11:12:33	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name://bin/dbus-daemon	<button>Authorize</button>
NIST EL Collaborative Robots Sys All segments Robotic Driver	02/20/2018 11:12:05	Installed Base Mismatch	Installed Base Mismatch : Unknown Process detected Process Name:[dpkg]	<button>Authorize</button>

1138

Source IP Source MAC	Destination Destination MAC	Protocol Type	Start Timestamp	End Timestamp	Packets/second	kBits/second
192.168.1.5 a0:ce:c8:1fb9:99	91.169.94.25 94:b8:c5:0e:e1:9f	HTTP	02/20/2018 11:12:05	02/20/2018 11:13:08	0.03	0.00

1139

### 1140 B.3.8. Unauthorized PLC Logic Download

1141 Many PLCs enable remote access for uploading and downloading control logic to and from the controller. This service provides great convenience, but also provides a mechanism for attackers to remotely access the control logic and proprietary manufacturing information if the PLC is not protected.

1145 This anomaly was executed on the PCS. The Allen-Bradley software Studio 5000 was used to download the logic from the PCS PLC to the engineering workstation. Physical access to the PLC was required in order to change the operation mode from RUN to REMOTE RUN.

NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:24:41	Abnormal communication pattern on a specific protocol between IP addresses	The communication between two IP addresses on a specific protocol is high in both number of packets and traffic bandwidth usage	Source IP: 172.16.2.102 Destination IP: 172.16.3.10 Source MAC Address: 00:1d:9c:c9:6d:42 Destination MAC Address: e4:90:69:3b:c2:c5 Protocol: CIP [ 41(kbps) > 0(kbps) ] [ 157(pps) > 0(pps) ]	<button>Authorize</button>
NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:24:41	Abnormal communication pattern on a specific protocol between IP addresses	The communication between two IP addresses on a specific protocol is low in traffic bandwidth usage	Source IP: 172.16.2.4 Destination IP: 172.16.3.10 Source MAC Address: 0c:c4:7a:31:44:bd Destination MAC Address: e4:90:69:3b:c2:c5 Protocol: TCP [ 0(kbps) < 1(kbps) ]	<button>Authorize</button>

1148

### 1149 B.3.9. Unauthorized PLC Logic Modification

1150 As previously mentioned, many PLCs enable remote access for uploading and downloading control logic to and from the controller. This service provides great convenience, but also provides a mechanism for attackers to replace valid control logic with malicious logic if the device is not protected.

1154 This anomaly was executed on the PCS. The Allen-Bradley software Studio 5000 was used to upload new logic from the engineering workstation to the PCS PLC. Physical access to the PLC was required in order to change the operation mode from RUN to REMOTE RUN.

NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:27:49	Abnormal communication pattern on a specific protocol between IP addresses	The communication between two IP addresses on a specific protocol is high in both number of packets and traffic bandwidth usage	Source IP: 172.16.3.10 Destination IP: 172.16.2.102 Source MAC Address: 40:a8:f0:3d:48:ae Destination MAC Address: e4:90:69:3b:c2:c0 Protocol: CIP [ 50(kbps) > 0(kbps) ] [ 19(pps) > 0(pps) ]	<button>Authorize</button>
NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:27:49	Abnormal communication pattern on a specific protocol between IP addresses	The communication between two IP addresses on a specific protocol is high in both number of packets and traffic bandwidth usage	Source IP: 172.16.3.10 Destination IP: 172.16.2.102 Source MAC Address: e4:90:69:3b:c2:c5 Destination MAC Address: 00:1d:9c:c9:6d:42 Protocol: CIP [ 99(kbps) > 0(kbps) ] [ 37(pps) > 0(pps) ]	<button>Authorize</button>
NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:27:49	Abnormal communication pattern between IP addresses	The communication between two IP addresses is high in terms of both packet and traffic bandwidth usage	Source IP: 172.16.3.10 Destination IP: 172.16.3.10 Source MAC Address: 00:1d:9c:c9:6d:42 Destination MAC Address: e4:90:69:3b:c2:c5 [ 37(kbps) > 0(kbps) ] [ 125(pps) > 0(pps) ]	<button>Authorize</button>
NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:27:49	Abnormal communication pattern between IP addresses	The communication between two IP addresses is high in terms of both packet and traffic bandwidth usage	Source IP: 172.16.3.10 Destination IP: 172.16.2.102 Source MAC Address: 40:a8:f0:3d:48:ae Destination MAC Address: e4:90:69:3b:c2:c0 [ 50(kbps) > 0(kbps) ] [ 19(pps) > 0(pps) ]	<button>Authorize</button>
NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:27:49	Abnormal communication pattern between IP addresses	The communication between two IP addresses is high in terms of both packet and traffic bandwidth usage	Source IP: 172.16.3.10 Destination IP: 172.16.2.102 Source MAC Address: e4:90:69:3b:c2:c5 Destination MAC Address: 00:1d:9c:c9:6d:42 [ 99(kbps) > 0(kbps) ] [ 37(pps) > 0(pps) ]	<button>Authorize</button>

1157

### B.3.10. Unauthorized Connection Is Established Between ICS Devices

1158 An unauthorized connection between two ICS devices may indicate anomalous activity and  
1159 is important to discover, especially when the devices do not normally communicate.

1160 The anomaly was executed on the PCS. An unauthorized remote desktop session was  
1161 initialized from the human-machine interface (HMI) server to the object linking and  
1162 embedding for process control (OPC) server. Valid credentials were used to complete the  
1163 connection.  
1164

NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:45:34	Abnormal communication pattern on a specific protocol between IP addresses	The communication between two IP addresses on a specific protocol is high in traffic bandwidth usage	Source IP: 172.16.2.5 Destination IP: 172.16.1.4 Source MAC Address: 0c:47:a3:32:b3:01 Destination MAC Address: e4:90:69:3b:c2:c5 Protocol: TCP [ 116(kbps) > 109(kbps) ]	<button>Authorize</button>
NIST EL Process Control All Segments PCS NetMon	02/22/2018 16:45:34	Abnormal communication pattern on a specific protocol between IP addresses	The communication between two IP addresses on a specific protocol is high in traffic bandwidth usage	Source IP: 172.16.2.5 Destination IP: 172.16.1.4 Source MAC Address: e4:90:69:3b:c2:c4 Destination MAC Address: 0c:c4:7a:31:44:47 Protocol: TCP [ 77(kbps) > 73(kbps) ]	<button>Authorize</button>

1165

### B.3.11. Host-Based Firewall Is Disabled

1166 The host-based firewall is an important part of the overall network security strategy.  
1167 Attackers may attempt to disable the firewall to gain access to the host. Any change in the  
1168 operating state of the host-based firewall may indicate malicious activity.  
1169

1170 This anomaly was executed on the PCS. The engineering workstation utilized the Microsoft  
1171 Windows 7 OS, which included the Windows Firewall component. The Windows Firewall  
1172 was manually disabled and enabled to generate the anomaly.

All Segments	Engineering WS	02/23/2018 15:41:47	Windows firewall status	Windows firewall enabled
All Segments	Engineering WS	02/23/2018 15:41:45	Windows firewall status	Windows firewall enabled
All Segments	Engineering WS	02/23/2018 15:41:45	Security Policy Violation	Network Segment Security Policy Violation

1173

1174 **B.3.12. Host-Based Anti-Virus Software Is Disabled**

1175 The anti-virus software is an important part of the overall ICS security strategy. Attackers  
1176 may attempt to disable the anti-virus software to download malwares to the host. Any change  
1177 in the operating state of the anti-virus software may indicate malicious activity.

1178 This anomaly was executed on the PCS. Symantec Endpoint Protection anti-virus software  
1179 was installed and operational on the engineering workstation. The software was manually  
1180 disabled and enabled to generate the anomaly.

All Segments	Engineering WS	02/23/2018 15:43:07	Antivirus status	AntiVirus protection disabled
All Segments	Engineering WS	02/23/2018 15:43:07	Security Policy Violation	Network Segment Security Policy Violation

1181

1182 **B.3.13. Host Central Processing Unit Load Is Increased**

1183 Most hosts in the ICS environment are running a predefined set of tasks or schedules. The  
1184 system load of each host usually closely follows a routine or pattern. Any change or  
1185 deviation from the routine could indicate malicious activity or abnormal or fault behavior of  
1186 the ICS.

1187 This anomaly was executed on the PCS. The software Prime95 [20] was installed on the  
1188 engineering workstation to generate the anomaly. The Prime95 torture test option “Blend”  
1189 was used to execute a search for large prime numbers, resulting in a central processing unit  
1190 utilization increase that was continuously greater than 95 percent.

NetworkSegment	Host	Timestamp (Detector)	Type	Description
Any All Segments	All Segments:HMI Host All Segments:Controller All Segments:Historian VM All Segments:OPC DA Server All Segments:Engineering WS	From  To	Any Agent started Detector started USB event CPU load	Free text search
All Segments	Engineering WS	02/27/2018 11:41:16	CPU load	CPU usage normal CPU Load: 32%
All Segments	Engineering WS	02/27/2018 11:38:44	CPU load	CPU usage increased CPU Load: 99%
All Segments	Engineering WS	02/27/2018 11:27:39	CPU load	CPU usage normal CPU Load: 31%

1191

1192 **B.3.14. Unauthorized Detachment of Keyboard to Host**

1193 While access to unused Universal Serial Bus (USB) ports can be denied through numerous  
1194 physical means, the potential may still exist for an attacker to simply remove an attached  
1195 USB device to gain access to a USB port. Detection of the disconnection of an input device  
1196 may indicate malicious activity.

1197 This anomaly was executed on the PCS. A USB keyboard attached to the engineering  
1198 workstation was temporarily disconnected from the USB port.

NIST EL Process Control All Segments Engineering WS	02/27/2018 11:47:18	Security Policy Violation	Security Policy Violation : USB Event : Device Inserted Site Security Policy Violation (Device class: Device)	Authorize
NIST EL Process Control All Segments Engineering WS	02/27/2018 11:47:10	Security Policy Violation	Security Policy Violation : USB Event : Device Removed Site Security Policy Violation (Device class: Device)	Authorize

1199

1200    **B.3.15. Unauthorized Insertion of USB Storage Device**

1201    Portable USB storage devices could be a threat to the ICS. An unauthorized USB device may  
1202    contain malware. Once inserted into a host, the malware can potentially gain control of the  
1203    host and infect other hosts in the ICS network.

1204    This anomaly was executed on the PCS. A USB storage device (flash drive) was temporarily  
1205    connected to the engineering workstation.

Host	Timestamp	Type	Description	Authorization
NIST EL Process Control All Segments Engineering WS	02/27/2018 11:19:01	Security Policy Violation	Security Policy Violation : USB Event : Device Inserted Site Security Policy Violation (Device class: Device)	<button>Authorize</button>
NIST EL Process Control All Segments Engineering WS	02/27/2018 11:18:56	Security Policy Violation	Security Policy Violation : USB Event : Device Removed Site Security Policy Violation (Device class: Device)	<button>Authorize</button>

1206

1207    **Appendix C. CyberX Supplemental Information**

1208    The CyberX platform delivers continuous operational technology (OT) threat monitoring and  
1209    asset discovery, combining a deep understanding of industrial protocols, devices, and  
1210    applications with OT-specific behavioral analytics, threat intelligence, risk and vulnerability  
1211    management, and automated threat modeling. The platform is delivered as a preconfigured  
1212    appliance, including the Internet Protocol (IP) address, subnet mask, default gateway, and  
1213    Domain Name System (DNS) servers utilized in the build environment.

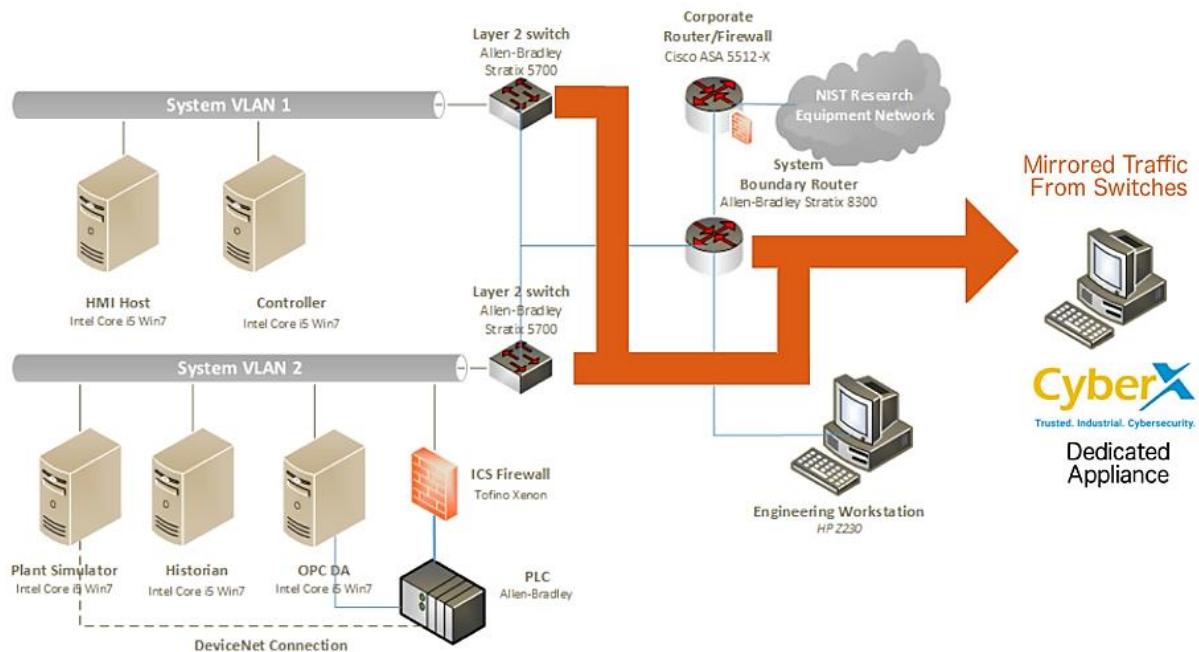
1214    **C.1. Build Architecture**

1215    The CyberX appliance was physically installed in the measurement rack of the Cybersecurity  
1216    for Smart Manufacturing Systems (CSMS) environment. Three existing Switch Port  
1217    Analyzer (SPAN) ports from each system (collaborative robotic system [CRS] and process  
1218    control system [PCS]) were connected to dedicated network interfaces on the appliance, for a  
1219    total of six SPAN ports. The SPAN port connections to the appliance, within the PCS and  
1220    CRS networks, are shown in Figure C-1 and Figure C-2, respectively.

1221    Enterprises typically deploy multiple CyberX appliances across various geographically  
1222    distributed sites, along with a central manager that is used to aggregate asset, vulnerability,  
1223    and threat information from each CyberX appliance, and to manage software updates and  
1224    configurations for each individual appliance.

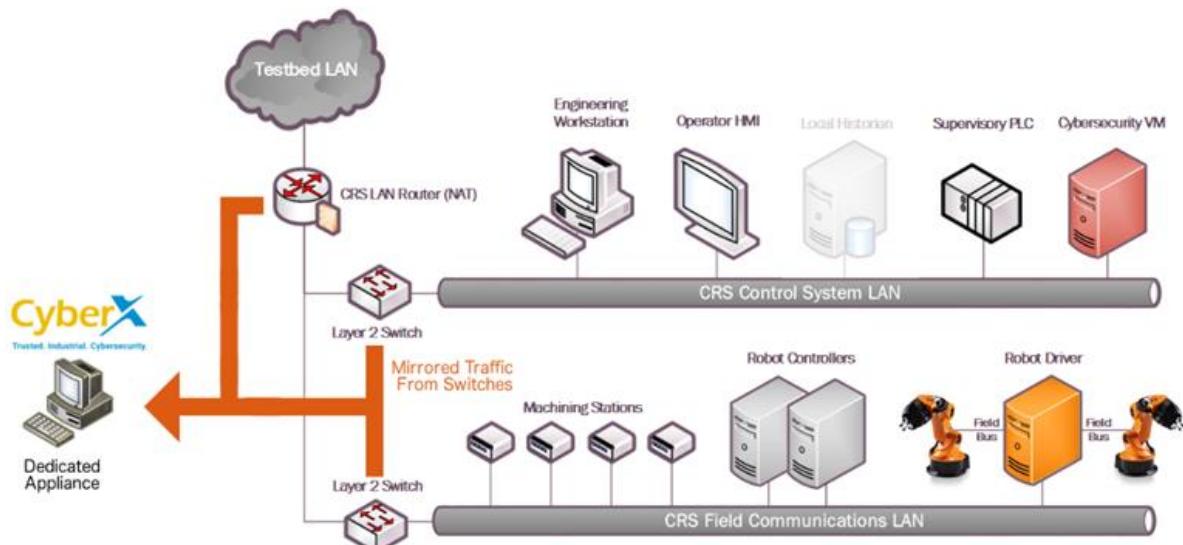
1225    The appliance network was connected to the demilitarized zone (DMZ) network located in  
1226    the test bed's measurement rack, to isolate the appliance's network traffic from the rest of the  
1227    network traffic. Engineering laptops were used to interface with the CyberX console  
1228    graphical user interface (GUI) via physical connections to the DMZ. More information  
1229    regarding the specific configuration of the test-bed network can be found in Section 3.

1230 **Figure C-1 SPAN Port Connections to the CyberX Appliance in the PCS**



1231

1232 **Figure C-2 SPAN Port Connections to the CyberX Appliance in the CRS**



1233

## 1234 **C.2. Installation and Configuration**

1235 Physical hardware and software were provided by CyberX for this demonstration. After the  
 1236 hardware appliance was received, it was installed into the CSMS test bed. Soon after the  
 1237 initial installation, engineers from CyberX arrived on site to complete the installation and  
 1238 configuration of the product. The following subsections describe the steps taken to install and  
 1239 configure the appliance.

1240   **C.2.1. Configuration Guide**  
1241   The CyberX appliance was received preconfigured for the build environment, with the proper  
1242   IP address, subnet mask, default gateway, and DNS server. If reconfiguration is needed, then  
1243   access the server via the command line and type the following command:

1244   > cyberx-xsense-network-reconfigure

1245   This will open a dialog for the configuration, similar to the dialog shown in Figure C-3.

1246   **Figure C-3 CyberX Network Reconfiguration Program on the Appliance**

```
configure management network IP address
Please type management network IP address: 192.168.1.1
invalid input. please try again: 192.168.1.1

configure subnet mask
Please type subnet mask: 255.255.255.0

configure DNS
Please type DNS: 127.0.0.1

configure default gateway IP address
Please type default gateway IP address: 192.168.1.2
```

1247  
1248   **C.2.2. Configuration of Forwarding Rules**  
1249   The CyberX platform is typically combined with an existing security information and event  
1250   management (SIEM) system. The following steps describe the process to forward data from  
1251   CyberX to the SIEM:

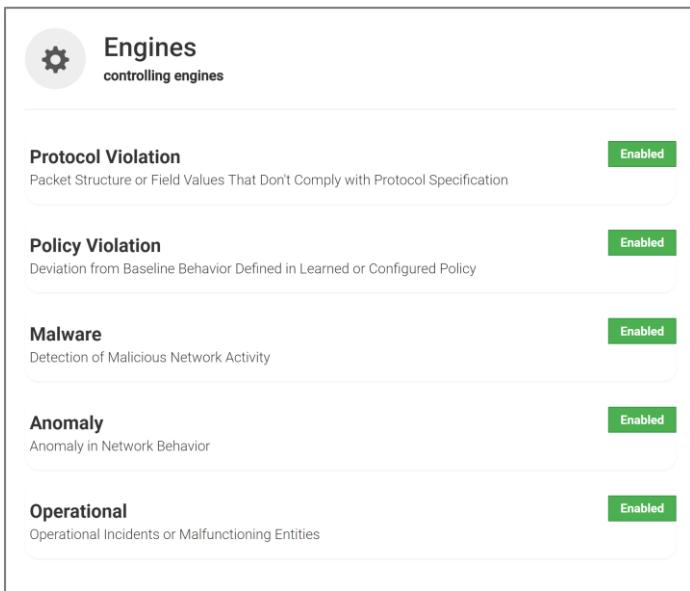
- 1252   1. Select **Forwarding** from the navigation menu on the CyberX console.
- 1253   2. Select **Create Forwarding Rule**.
- 1254   3. Complete the required information for the Forwarding Rule, and then select **Submit**.

1255   **C.2.3. Enabling Self-Learning Analytics**

1256   The CyberX platform has five different self-learning analytics engines that are used to detect  
1257   various types of behavioral anomalies within the network. The following steps describe the  
1258   process to enable individual analytics engines:

- 1259   1. Select **System Settings** from the navigation menu on the CyberX console.
- 1260   2. Click the **Enabled/Disabled** button next to each engine to enable or disable the  
1261   engine. If an engine is enabled, then the button will indicate **Enabled** and will be  
1262   illuminated with a green background color. An example with all five engines enabled  
1263   is shown in Figure C-4.

1264 **Figure C-4 Example Screenshot with All Five Self-Learning Analytics Enabled**



1265

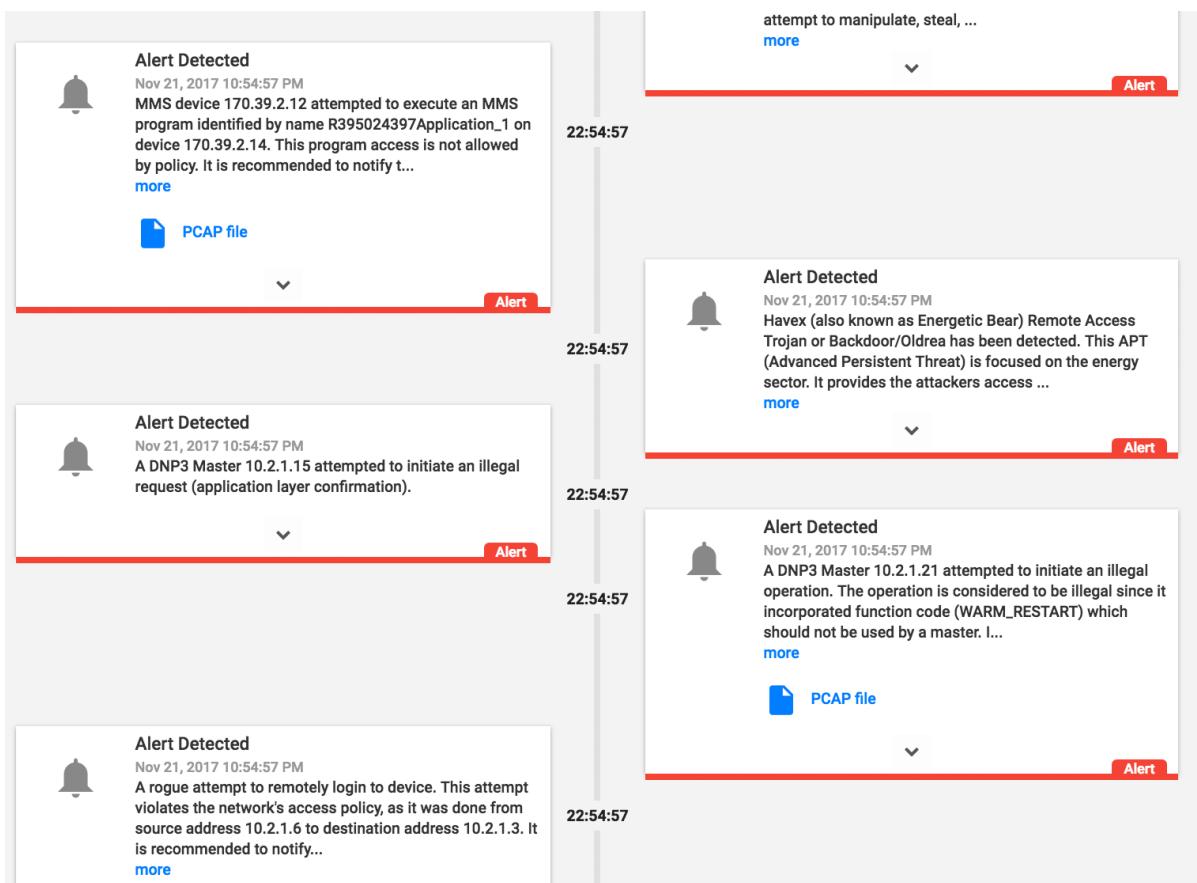
1266 **C.3. Anomaly Scenarios**

1267 The network-based anomaly detection method was demonstrated for the scenarios detailed in  
1268 the following subsections. Each scenario includes a description of the anomaly, a detailed  
1269 description of how each demonstration event was conducted in the CSMS environment, and  
1270 the observed results.

1271 For the sake of brevity, only a subset of the alerts observed during the demonstration is  
1272 shown. However, each anomaly scenario includes a screenshot of the alerts summary  
1273 observed after the anomaly scenario had completed.

1274 Alerts can be observed in the Alerts dashboard, grouped by the severity and type of alert, as  
1275 well as in the Event Log (timeline view). The Event Log view is shown in the screenshot in  
1276 Figure C-5.

1277 **Figure C-5 Event Log (Timeline View) of Real-Time Alerts in the CyberX Console**



1278

1279 **C.3.1. Unencrypted Hypertext Transfer Protocol Credentials Are Detected on**  
1280 **the Network**

1281 Unencrypted or plaintext credentials transmitted over a network are a vulnerability for  
1282 industrial control systems (ICS) networks. If packets containing these credentials are  
1283 intercepted, then the credentials can be easily unmasked and can be used to obtain  
1284 unauthorized access to devices or services that use those credentials. This vulnerability can  
1285 be amplified if multiple devices utilize the same credentials.

1286 This anomaly was executed on the CRS. An Apache [17] Hypertext Transfer Protocol  
1287 (HTTP) server was configured on Machining Station 1 and contained a directory that was  
1288 protected by HTTP basic authentication. The web pages hosted in the protected directory  
1289 enabled an operator to remotely view machine status information. The connection was  
1290 initiated from the Firefox browser on the engineering workstation.

14:03:24

**HTTP Basic Authentication**  
Jan 11, 2018 2:03:24 PM  
Client device 192.168.0.20 authenticated to HTTP server  
192.168.0.98 using cleartext password via HTTP basic authentication

Devices

Type	Name
Unknown	POLARIS
HMI	192.168.0.98

[Filter events by related devices](#) [Info](#)

1291

### 1292 **C.3.2. Unauthorized Secure Shell Session Is Established with an Internet-Based Server**

1293 A Secure Shell (SSH) session is an encrypted and secure connection for remotely sending  
1294 commands over a network. However, unauthorized SSH sessions with internet-based servers  
1295 could indicate malicious activity. Attackers can use an SSH session to gain access to the ICS  
1296 device and network.

1297 This anomaly was executed on the PCS. The OpenSSH [21] suite was installed and  
1298 configured on a server with an internally routed public IP address (129.6.1.2). The  
1299 open-source SSH client PuTTY [12] was used to establish a connection with the SSH service  
1300 from the engineering workstation to the internet-based server.

15:43:26

**Remote Access Connection Established**  
Jan 16, 2018 3:43:26 PM  
Connection detected from 172.16.3.10 to 129.6.1.2 using SSH

Devices

Type	Name
HMI	FGS-47631EHH
Internet	Internet

[Filter events by related devices](#) [Info](#)

1301

### 1302 **C.3.3. Data Exfiltration to the Internet via DNS Tunneling**

1303 Attacks against ICS, with the goal of information gathering, must (at some point) attempt to  
1304 exfiltrate sensitive or proprietary data from the ICS network, potentially utilizing the internet  
1305 as a transport mechanism. Monitoring for ICS devices communicating to other devices over  
1306 the internet can help detect data exfiltration events, especially if the affected device does not  
1307 normally communicate over the internet.

1308 This anomaly was executed on the CRS. A script was written in Python [14] to exfiltrate the  
1309 file contents via DNS tunneling. The DNS request functionality was enabled by the Linux  
1310 command-line tool nslookup. A DNS Type A record was added to the test-bed DNS  
1311 server, mapping the \*.nist.gov domain to our local internet-based server IP address  
1312 (129.6.1.2).

1313 To exfiltrate the file, the Python script would first read 30 bytes from the file  
1314 measurements.cmm, convert the bytes into a hexadecimal representation encoded as an  
1315 American Standard Code for Information Interchange string, and concatenate the string as a  
1316 subdomain with the Uniform Resource Identifier (URI) .nist.gov. The resulting URI is  
1317 sent to the nslookup tool, which subsequently transmitted the DNS request. This process  
1318 repeated until the complete file contents were exfiltrated.

The screenshot shows a security alert interface. At the top left is a bell icon with the text "Alert Detected" and the date "Jan 18, 2018 11:19:20 AM". The main message reads: "DNS client 192.168.0.20 sent a name query of type A to resolve name 202020302e30303036c39020c390202031393520c3900a.nist.gov which is not allowed by policy. It is recommended to notify the security off...". Below this is a blue "PCAP file" link. To the right, the timestamp "11:19:20" is displayed vertically. In the center, there's a "Related Alerts" section with a box containing "POLICY Unauthorized DNS Name Query | 4 minutes ago" and "VIOLATION DNS client 192.168.0.20 sent a name query of type A to res...". Below this is a "Devices" section with a table:

Type	Name
Domain Controller	LAN-AD
Unknown	POLARIS

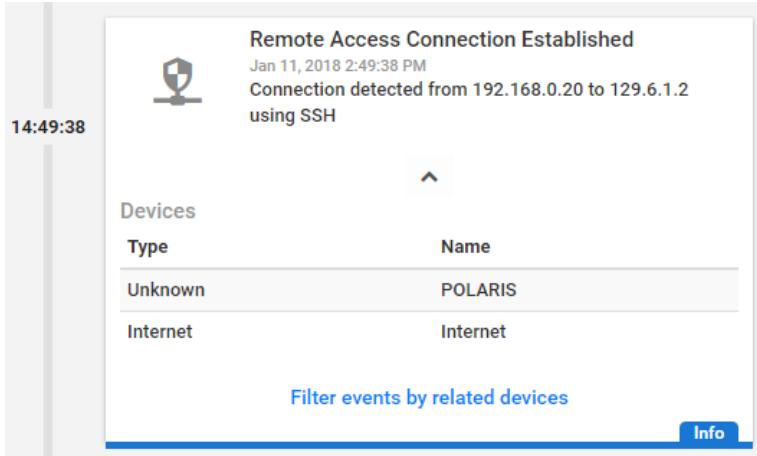
At the bottom, there's a blue "Filter events by related devices" link and a red "Alert" button.

1319

### 1320 C.3.4. Data Exfiltration to the Internet via Secure Copy Protocol

1321 As previously mentioned, attacks against ICS, with the goal of information gathering, must  
1322 (at some point) attempt to exfiltrate the data from the ICS network, potentially utilizing the  
1323 internet as a transport mechanism. Monitoring for ICS devices communicating to other  
1324 devices over the internet can help detect data exfiltration events, especially if the affected  
1325 device does not normally communicate over the internet. Depending on the protocol used for  
1326 exfiltration, the file contents and/or data being exfiltrated may be ascertainable (e.g., specific  
1327 file types transferred using the File Transfer Protocol [FTP] protocol), providing insight into  
1328 the impact of the event.

1329 This anomaly was executed on the CRS. The OpenSSH [21] suite was installed and  
1330 configured on a server with an internally routed public IP address (129.6.1.2). The secure  
1331 copy protocol was then used to transfer a sensitive file over SSH from the engineering  
1332 workstation to the internet.



1333

### 1334 **C.3.5. European Institute for Computer Antivirus Research Virus Test File Is** 1335 **Detected on the Network**

1336 Malware and computer viruses are serious threats to ICS. Malware can undermine ICS  
1337 security, confidentiality, and stability, with the potential to sabotage the ICS. Providing the  
1338 ability to detect the presence of viruses and malware in the ICS network is important for  
1339 minimizing risk to the manufacturing system.

1340 This anomaly was executed on the PCS. The European Institute for Computer Antivirus  
1341 Research (EICAR) virus test file was transferred from the human-machine interface (HMI)  
1342 server to the object linking and embedding for process control (OPC) server by using  
1343 Windows File Sharing (Server Message Block protocol).

6:17:23

 Alert Detected  
Jan 16, 2018 4:17:23 PM  
EICAR AV Test File was detected in traffic between 129.6.1.2 and 172.16.3.10. This file is used to check anti-virus engines and does not contain any virus or fragments of harmful code.

 PCAP file

Related Alerts

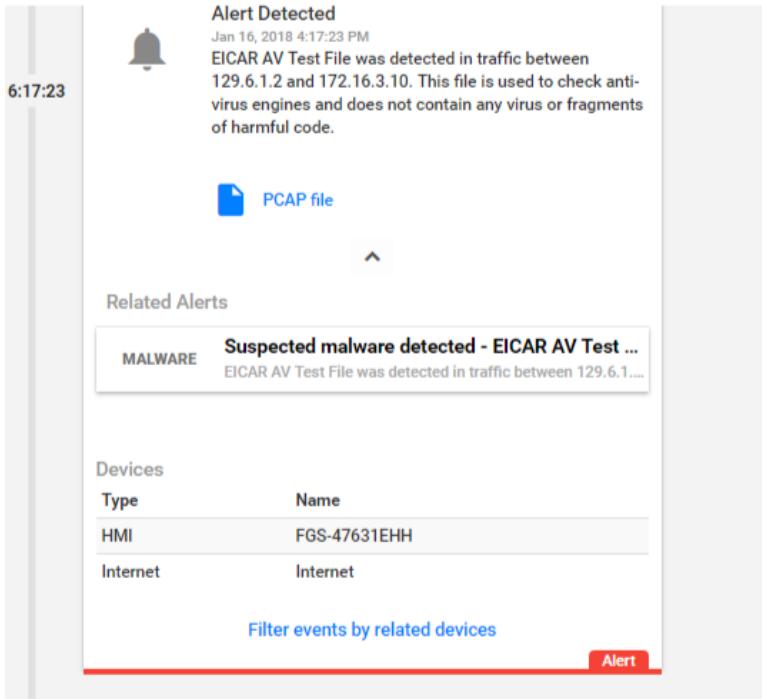
**MALWARE Suspected malware detected - EICAR AV Test ...**  
EICAR AV Test File was detected in traffic between 129.6.1....

Devices

Type	Name
HMI	FGS-47631EHH
Internet	Internet

[Filter events by related devices](#)

Alert



1344

### C.3.6. Unauthorized Device Is Connected to the Network

It is important to identify all devices on the ICS network, for a complete risk analysis and for minimizing potential attack vectors. The detection of unauthorized devices attached to the ICS network may indicate anomalous activity. These unauthorized devices are important to find and remove, especially because the purpose of an unauthorized device is unknown and may be malicious.

This anomaly was executed on the PCS. The engineering laptop (Windows 7 operating system) was removed from the network during the baseline analysis phase of the product and was later connected to Virtual Local Area Network (VLAN)-2 to execute the anomaly. After the initial connection, background traffic was automatically generated onto the network by the laptop.

7

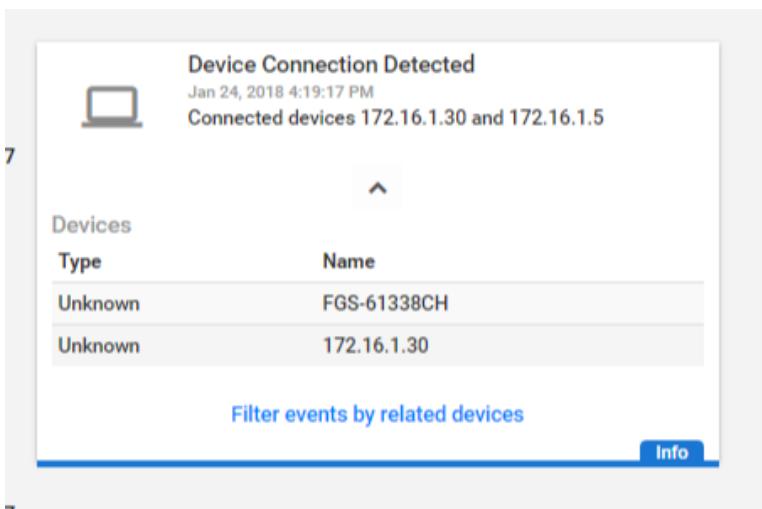
 Device Connection Detected  
Jan 24, 2018 4:19:17 PM  
Connected devices 172.16.1.30 and 172.16.1.5

Devices

Type	Name
Unknown	FGS-61338CH
Unknown	172.16.1.30

[Filter events by related devices](#)

Info



1356

1357 **C.3.7. Denial-of-Service Attack Is Executed Against the ICS Local Area Network**

1358 Disruptive attacks, like a denial of service (DoS), are a serious threat to ICS, especially ICS  
1359 that rely heavily on networks to communicate. An attacker can launch a DoS attack on ICS  
1360 and disrupt normal operations, with potentially debilitating effects to the system. The ability  
1361 to detect such attacks is important to protect the manufacturing system.

1362 This anomaly was executed on the PCS. The Linux **ping** command-line tool was used to  
1363 transmit a flood of Internet Control Message Protocol (ICMP) packets to the OPC server.  
1364 The anomaly utilizes **ping**'s **flood** flag to inundate the OPC server with ICMP packets.  
1365 Each ICMP packet requires fragmentation, due to its large size (3,000 bytes), configured  
1366 using the packet-size flag.

Alert Report

Anomaly | 01/17/2018 11:01:12

ID: 1206

ICMP Flooding

An abnormal quantity of ICMP traffic was detected in the network which could be the result of an ICMP flooding attack. Number of ICMP packets detected was: 65.

1367

1368 **C.3.8. Data Exfiltration Between ICS Devices via User Datagram Protocol**

1369 An unauthorized file transfer between two ICS devices could indicate anomalous activity and  
1370 is important to identify, especially when the devices do not normally communicate or when  
1371 the exchange of files is unauthorized.

1372 This anomaly was executed on the CRS. A tape archive file was transmitted from the  
1373 cybersecurity virtual machine (CybersecVM) to the engineering workstation by using the  
1374 Linux utility netcat and User Datagram Protocol (UDP) sockets. UDP Port 9999 was used for  
1375 the transfer.

12:55:28

**Alert Detected**  
Jan 18, 2018 12:55:28 PM  
A service not allowed by policy has been detected. Client: 192.168.0.20, Server: 129.6.1.2

 PCAP file

**Related Alerts**

POLICY	<b>Service Mapping</b>   2 minutes ago
VIOLATION	A service not allowed by policy has been detected. Client: 1...

**Devices**

Type	Name
Unknown	POLARIS
Internet	Internet

[Filter events by related devices](#)

**Alert**

1376

1377 **C.3.9. Invalid Credentials Are Used to Access a Networking Device**

1378 Authentication systems that are not rate-restricted may be vulnerable to password-guessing  
1379 attacks, especially if the default credentials of the device have not been changed. Compiled  
1380 lists containing default user credentials are freely available on the internet, as are lists of  
1381 commonly used usernames and passwords. Given enough time, an attacker may be able to  
1382 access vulnerable systems by using a brute-force password attack.

1383 This anomaly was executed on the PCS. The Allen-Bradley software Studio 5000 was used  
1384 to download the logic from the PCS programmable logic controller (PLC) to the engineering  
1385 workstation. Physical access to the PLC was required in order to change the operation mode  
1386 from RUN to REMOTE RUN.

Jan 17, 2

**i Telnet Authentication Failure**

Jan 17, 2018 2:51:38 PM

A failed login attempt occurred from device 172.16.3.10 to Telnet server 172.16.1.3

This might be related to a human error, but it could also indicate a malicious attempt to manipulate, steal, or damage important data. It is recommended to notify the security officer of the incident.

^

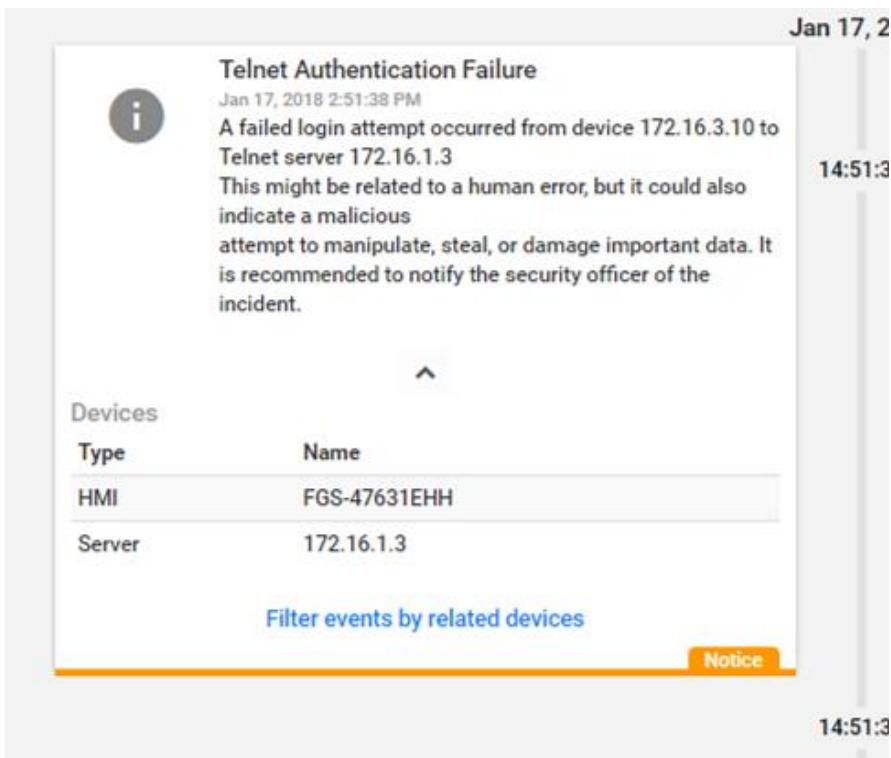
**Devices**

Type	Name
HMI	FGS-47631EHH
Server	172.16.1.3

[Filter events by related devices](#)

**Notice**

14:51:3



1387

### 1388 C.3.10. Brute-Force Password Attack Against a Networking Device

1389 As previously mentioned, authentication systems that are not rate-restricted may be  
1390 vulnerable to password-guessing attacks, especially if the default credentials of the device  
1391 have not been changed. Compiled lists containing default user credentials are freely available  
1392 on the internet, as are lists of commonly used usernames and passwords. Given enough time,  
1393 an attacker may be able to access vulnerable systems by using a brute-force password attack.

1394 This anomaly was executed on the PCS. The software Nmap [16] was used to generate the  
1395 brute-force password attack by using the script **telnet-brute**. The attack was pointed at  
1396 the PCS router, which has a Telnet service for remote configuration and is protected by a  
1397 password. The service was not configured to limit the number of authentication attempts.

**Alert Detected**  
Jan 17, 2018 3:22:43 PM  
Device 10.100.0.28 attempted to authenticate with Server 172.16.1.3 on port 23 using different default credentials more frequently than expected.  
This could represent suspicious behavior.  
It is recommended to notify the security officer about the incident.

**PCAP file**

**Related Alerts**

ANOMALY	<b>Password Guessing Attempt Detected</b>   just now Device 10.100.0.28 attempted to authenticate with Server 1...
---------	---

**Devices**

Type	Name
Server	10.100.0.28
Server	172.16.1.3

1398

1399 **C.3.11. Unauthorized PLC Logic Download**

1400 Many ICS devices provide services to remotely update control logic over the network. These  
1401 network services can also provide a mechanism for attackers to replace valid control logic  
1402 with malicious logic if the device is not protected.

1403 This anomaly was executed on the PCS. The Allen-Bradley software Studio 5000 was used  
1404 to download the logic from the PCS PLC to the engineering workstation. Physical access to  
1405 the PLC was required in order to change the operation mode from RUN to REMOTE RUN.

The screenshot shows a log entry for a PLC Program Upload. The event occurred on Jan 17, 2018, at 4:34:23 PM. It details that Device 172.16.3.10 sent a command to read the program of PLC 172.16.2.102 by uploading code from the device, using EtherNet/IP protocol, service Read on class UserTemplate. Below this, there is a table titled 'Devices' showing two entries: an HMI named FGS-47631EHH and a PLC with IP address 172.16.2.102. A link 'Filter events by related devices' is present. A 'Notice' button is located at the bottom right of the log entry.

1406

### 1407 C.3.12. Unauthorized PLC Logic Update – CRS

1408 Many ICS devices provide services to remotely update control logic over the network. These  
1409 network services can also provide a mechanism for attackers to replace valid control logic  
1410 with malicious logic if the device is not protected.

1411 This anomaly was executed on the CRS. The TwinCAT eXtended Automation Engineering  
1412 (XAE) software from Beckhoff was used to deploy new logic to the CRS PLC. The  
1413 deployment was performed by using the engineering laptop while the PLC was in the  
1414 ONLINE mode. The unauthorized logic was functionally compatible with the authorized  
1415 logic that it replaced, with minor modifications.

14:28:59

**Alert Detected**

 Jan 16, 2018 2:28:59 PM  
PLC 192.168.0.30 was programmed from device 192.168.0.147 using protocol AMS, which is not defined as a Programming Device.  
This is not allowed by policy.  
It is recommended to notify the security offi...  
[more](#)

Related Alerts

**POLICY    Unauthorized PLC Programming | 1 minute ago**  
**VIOLATION**    PLC 192.168.0.30 was programmed from device 192.168.0....

Devices

Type	Name
Engineering Station	192.168.0.30
PLC	192.168.0.147

[Filter events by related devices](#)

Alert

1416

1417 **C.3.13. Unauthorized PLC Logic Update – PCS**

1418 As previously mentioned, many ICS devices provide services to remotely update control  
1419 logic over the network. These network services can also provide a mechanism for attackers to  
1420 replace valid control logic with malicious software if the device is not protected.

1421 This anomaly was executed on the PCS. The Allen-Bradley software Studio 5000 was used  
1422 to upload new logic from the engineering workstation to the PCS PLC. Physical access to the  
1423 PLC was required in order to change the operation mode from RUN to REMOTE RUN.

:33

**Alert Detected**

Jan 17, 2018 4:36:33 PM

PLC 172.16.2.102 was programmed from device 172.16.3.10 using protocol ETHERNET/IP, which is not defined as a Programming Device.

This is not allowed by policy.

It is recommended to notify the securit...

[more](#)

 [PCAP file](#)

Related Alerts

**POLICY VIOLATION Unauthorized PLC Programming | 4 minutes ago**

PLC 172.16.2.102 was programmed from device 172.16.3.1...

Devices

Type	Name
HMI	FGS-47631EHH
PLC	172.16.2.102

[Filter events by related devices](#)

1424

1425 **C.3.14. Undefined Modbus Transmission Control Protocol Function Codes Are**  
1426 **Transmitted to the PLC**

1427 Communications that do not conform to the defined specifications of the industrial protocol  
1428 may cause an ICS device to act in an undefined or unsafe manner. Depending on the  
1429 manufacturing process and the ICS device, the nonconforming communications may or may  
1430 not be impactful, but investigation into the cause is warranted.

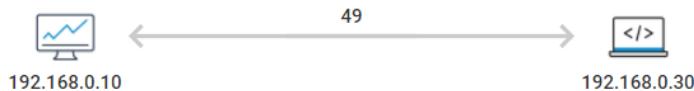
1431 This anomaly was executed on the CRS. Python [14] was used to create a Modbus  
1432 Transmission Control Protocol (TCP) message with the undefined function code value of 49  
1433 (0x31). The message was generated by the CybersecVM and was transmitted to the PLC  
1434 Modbus server.

ID: 1512

## Unpermitted Usage of Modbus Function Code

Policy Violation | Jan 18, 2018 1:48:18 PM ( 2 minutes ago )

MODBUS device 192.168.0.10 attempted to initiate a Request (function code 49) which is not allowed by policy. It is recommended to notify the security officer of the incident.



### Mitigation

- Consult a relevant Control Systems Engineer to validate this infraction.

### Notifications

- PCAP file exists.
- If valid, CyberX platform can learn this behavior for future use, at 'Operations'.

1435

## 1436 C.3.15. Unauthorized Ethernet/IP Scan of the Network

1437 During the reconnaissance phase, an attacker may attempt to locate vulnerable services in an  
1438 ICS network and will likely include probing for ICS-specific services (e.g., Ethernet/IP).  
1439 Once a vulnerable service, host, or device is discovered, an attacker may attempt to exploit  
1440 that entity.

1441 This anomaly was executed on the PCS. The software Nmap [16] was used to perform a port  
1442 scan (Ports 1 through 1024) against two hosts: the HMI and the plant controller. The scan  
1443 originated from the CybersecVM, logically located in the test-bed local area network (LAN).

1444 This anomaly was executed on the PCS. The software Nmap [16] was used to perform an  
1445 Ethernet/IP device scan by using the script `enip-info`. The scan was pointed at the PCS  
1446 subnet 172.16.2.100/28 and was executed by the CybersecVM in the test-bed LAN.

**Alert Detected**

Jan 19, 2018 10:18:00 AM

Address scan detected.

Scanning address: 10.100.0.28

Scanned subnet: 172.16.0.0/16

Scanned addresses: 172.16.2.1, 172.16.2.10, 172.16.2.28, 172.16.2.37, 172.16.2.54...

It is recommended to notify the ...

[more](#)

 [PCAP file](#)

[^](#)

**Related Alerts**

**ANOMALY** [Address Scan Detected](#) | 2 minutes ago

Address scan detected. Scanning address: 10.100.0.28 Sca...

**Devices**

Type	Name
Server	10.100.0.28

[Filter events by related devices](#)

Alert1

1447

1448 **Appendix D. OSIsoft Process Information Supplemental Information**

1449 The OSIsoft Process Information (PI) System is a suite of software applications for  
1450 capturing, analyzing, and storing real-time data for industrial processes. Although the PI  
1451 System is typically utilized as a process historian, the PI System is also utilized to collect,  
1452 store, and manage data in real time. Interface nodes retrieve data from disparate sources to  
1453 the PI Server, where the PI Data Archive resides. Data is stored in the Data Archive and is  
1454 accessible in the assets defined in the Asset Framework (AF). Data is then typically accessed,  
1455 either directly from the Data Archive or from the AF Server, by using tools in the PI  
1456 visualization suite. Typically, most PI System users consume data by accessing the AF  
1457 Server, rather than directly accessing the Data Archive. This build demonstrates how PI can  
1458 be leveraged to monitor for specific behavioral anomalies of the process that may be caused  
1459 by cybersecurity incidents, and to alert operators and cybersecurity personnel of the  
1460 anomalies.

1461 **D.1. Build Architecture**

1462 The PI System was installed in a virtual environment (HyperV) that already existed within  
1463 the collaborative robotic system (CRS). The virtual machine (VM) for the PI System used  
1464 Windows Server 2008 R2 as the operating system, with four virtual central-processing-unit  
1465 cores and 16 gigabytes (GB) of random-access memory. The VM was networked directly  
1466 into the existing network topology of the CRS with a dedicated Internet Protocol (IP) address  
1467 (192.168.0.21).

1468 **D.2. Installation and Configuration**

1469 Compared with the other three installations, the PI System was installed locally on existing  
1470 virtualization hardware. Remote assistance and troubleshooting were provided by OSIsoft for  
1471 the installation and configuration of the system within the CRS.

1472 Six components were installed in the VM:

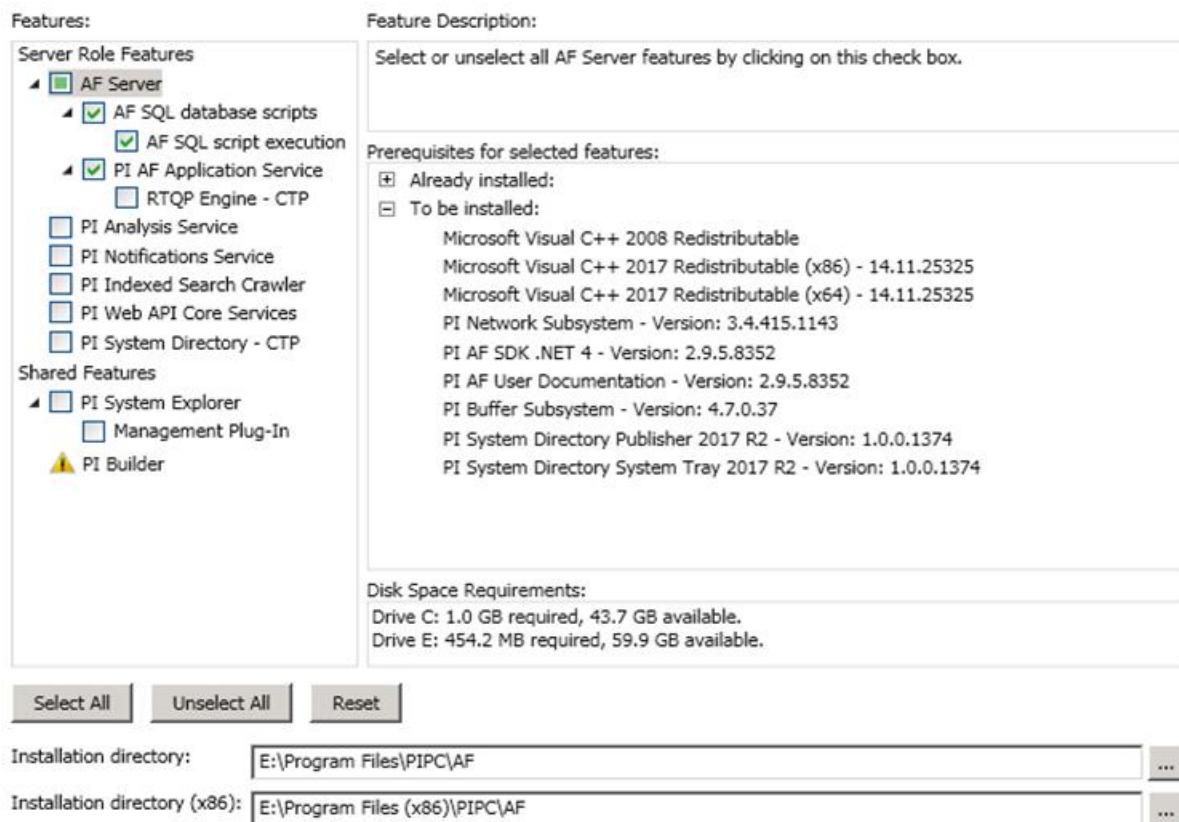
- 1473 • PI AF
- 1474 • PI Data Archive
- 1475 • PI Process Explorer
- 1476 • PI Vision
- 1477 • PI Modbus Ethernet Interface
- 1478 • Structured Query Language Server 2012

1479 Four additional hard-drive partitions (virtual) were created to support the PI System  
1480 installation:

- 1481 • PI Server (E): 60 GB
- 1482 • archives (F): 60 GB
- 1483 • queues (G): 30 GB
- 1484 • backups (H): 21 GB

- 1485    **D.2.1. PI AF Installation**
- 1486    1. Run *PI-AF-Services\_2017-R2-Update-1\_Demo.exe* to launch the installer.
- 1487    2. Select the **Server Role Features** shown in Figure D-1. Ensure that the **Installation Directory** is set to the corresponding drive letter labeled as *PI Server*. Click **Next**.

1489    **Figure D-1 Server Role Features to Be Selected During PI AF Installation**



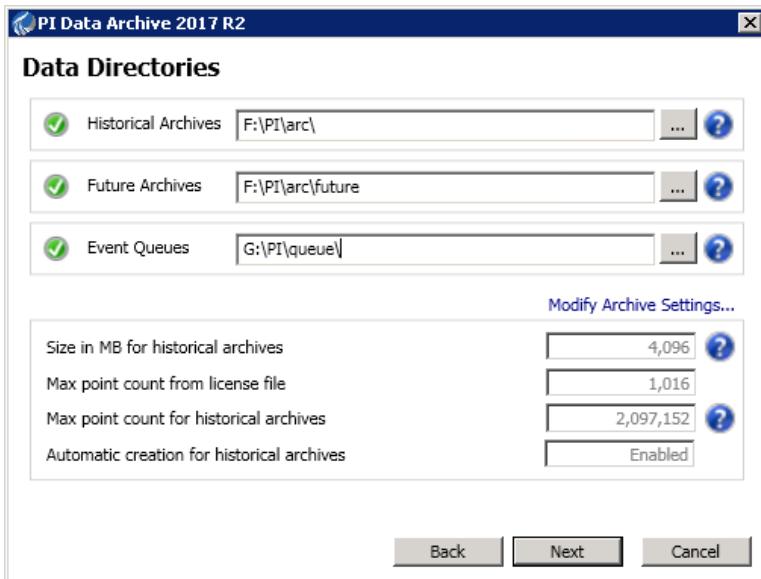
- 1490
- 1491    3. Keep the default settings. Click **Next**.
- 1492    4. Set the **Directory Name** to <Configure Later>. Click **Next**.
- 1493    5. Leave the **Service Account** as default. Click **Next**.
- 1494    6. Upon completed installation, reboot the server.

1495    **D.2.2. PI Data Archive Installation**

- 1496    1. Run the *PI-Data-Archive\_2017\_R2A\_Demo\_.exe* file.
- 1497    2. When prompted for the **License File**, browse to the location of the *pilicense.dat* file from OSIsoft. Click **Next**.
- 1498
- 1499    3. Specify a name for the **Default Asset server**, or leave it as the default host name. Click **Next**.
- 1500

- 1501     4. Select the **Installation Directory** for the Data Archive. Click **Next**.
- 1502     5. Set the remaining directories as shown in Figure D-2, corresponding to the correct  
1503       drive letters. Click Next.
- 1504     6. Click **Next**, and verify that the service status shows as **Running**. Click **Next** to finish  
1505       the installation and to reboot the server.

1506 **Figure D-2 Data Directories to Be Selected During PI Data Archive Installation**



- 1507
- 1508 **D.2.3. PI System Process Explorer Installation**
- 1509     1. Run the *PIPProcessBook\_2015\_R2\_SP1\_06-Jun-2018.exe* file to start the installation.
- 1510     2. A screen titled OSISoft Setup Progress will begin, installing the different required  
1511       components.
- 1512     3. A dialog box will appear once the installation is complete.
- 1513 **D.2.4. PI Vision Installation**
- 1514     1. Run the *PI-Vision\_2017-R2-Update-1-90-Day-Trial\_.exe* file to start the installation.
- 1515     2. Select the **Operating Configuration Store**. In this build, the Asset Server was called  
1516       PI-ROBOTICS. Click **Connect**, and then click **Next**.
- 1517     3. Verify that the **PI Web API port is 443**. Click **Next**.
- 1518     4. On the Submit URL page, do not change the automatically generated **Indexed**  
1519       **Search Crawler Submit URL**. In this build, the automatically generated Uniform  
1520       Resource Locator (URL) was *https://pi-robotics.lan.lab/piwebapi/*. Click **Next**.
- 1521     5. Review the changes. Click **Next**.

1522        6. When the installation has completed, review the Confirmation page for errors. If no  
1523        errors are found, then click **Finish**.

1524        7. The installer will continue installing additional components. Click **Continue** when  
1525        prompted to install Windows features.

1526        8. If prompted, leave the default installation directories. Click **Next**.

1527        9. Once the installation finishes, click **Finish**.

#### 1528      **D.2.5. PI System Modbus Ethernet Interface Installation**

1529        1. Run the *ModbusE\_ReadWrite\_4.2.2.31\_DEMO.exe* file to start the installation.

1530        2. Keep all default settings, and complete the installation.

1531        3. Open PI Interface Configuration Utility, and select the interface **PIModbusE1**.

1532        4. Configure the **Display Name**. In this build, the default name was kept.

1533        5. Select the option **Service** in the left navigation panel.

1534        6. Select the **Startup Type** option **Auto**, click **Create**, and then click **Apply**.

1535        7. Click the Start Service ( ) button on the top navigation bar.

1536        8. If the service is running properly, then the label **Running** will appear on the status bar  
1537        at the bottom of the dialog.

#### 1538      **D.2.6. PI System Points and Assets Configuration**

1539        PI System points utilizing the ModbusE interface were manually created using the PI System  
1540        Management Tools (SMT) software. Modbus device addresses, register names, and register  
1541        addresses were known prior to configuring the points.

1542        1. Launch the PI SMT by navigating to **Start > All Programs > PI System > PI**  
1543        **System Management Tools**.

1544        2. Select **Points > Points Builder** from the left navigation pane.

1545        3. Create a new tag, and enter the required attributes (shown in Figure D-3). An example  
1546        of the configuration for the Point PLC-ExperimentMode is shown in Figure D-4.

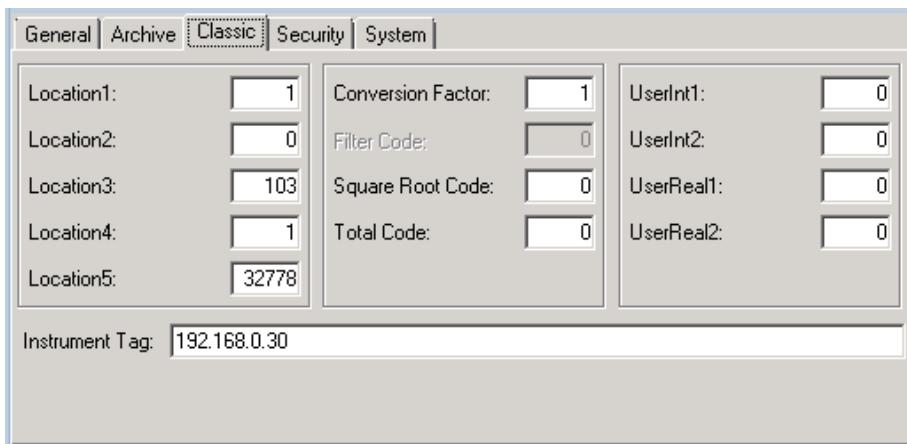
1547        4. Click **Save**.

1548      **Figure D-3 Configuration Options in the PI Point Builder for Tags Utilizing the ModbusE**  
 1549      **Interface**

Point Builder Tab	Field	Setting
General	Name	ModbusETest
	Point source	MODBUSE
	Point type	Int32
Classic	Location 1	1 (or whatever was used in the Interface ID field in PI ICU)
	Location 2	(Node ID). Example: 1
	Location 3	(Data Type * 100 + Function Code). Example: 103 (which is 1 (for Int16) * 100 + 3 (for holding registry)). Refer the interface manual for a full list of data types and function codes
	Location 4	1 (Scan class Frequency)
	Location 5	(offset from 40000 for holding registry). Example: 52 Represents 40052 register
	Instrument tag	IP address or hostname of the Ethernet communications node. Must match with the IP Addr./Hostname entered

1550

1551      **Figure D-4 Example Configuration Settings for the Tag PLC-ExperimentMode**



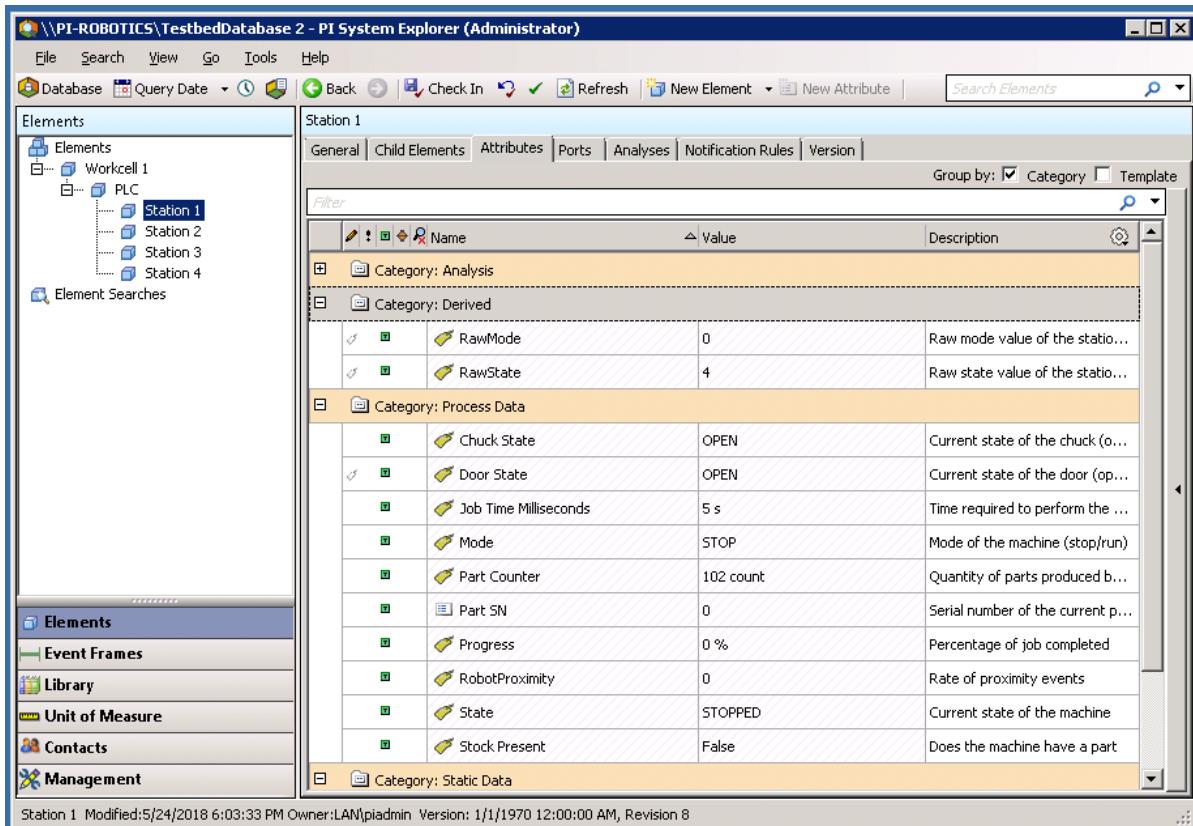
1552

1553      In Figure D-4, the fields **Location1** through **Location5** have different uses, depending on the  
 1554      interface used, and are described in detail in Figure D-3. The **Instrument Tag** field describes  
 1555      the IP address of the Modbus Transmission Control Protocol (TCP) server that the ModbusE  
 1556      interface needs to poll.

1557      The PI System AF and System Explorer were used to define a hierarchical structure for the  
 1558      PI System points, to display tag values for each asset, and to provide an interface for viewing  
 1559      and acknowledging alerts. Because of the relatively simple interactions among elements of  
 1560      the CRS, the structure created in the AF contained the supervisory programmable logic  
 1561      controller (PLC) as the top-level element, and Station 1 through Station 4 as child elements.

1562 Asset templates were created for the PLC and four machining stations to automatically link  
1563 to the proper PI System points based on the asset. The final configuration of assets is shown  
1564 in Figure D-5, showing the hierarchical structure of **Workcell 1 > PLC > Station 1**. Also  
1565 shown in this figure are the **Attributes** for Station 1, as received from the PI System points.

1566 **Figure D-5 PI System Explorer View Showing the Configured Assets (Elements), the Resulting**  
1567 **Hierarchical Structure of Assets, and Live Attributes Received from Station 1**



1568  
1569 For both the PLC and machining-station asset templates, analysis functions were created to  
1570 generate alerts for the operator when identified anomalous events are detected. The  
1571 anomalous events to be detected are the anomalies described in Section D.3. The analysis  
1572 functions are described in Sections D.2.7 and D.2.8. Respective event-frame generators for  
1573 each analysis function were created to generate the actual alerts.

#### 1574 **D.2.7. PLC Asset Template Analysis Functions**

1575 The analysis functions provided in the following subsections were created to generate alerts  
1576 in the PLC asset template when their respective anomalous events are detected. For the sake  
1577 of brevity, the event-frame generation code is not shown. In general, the typical event-frame  
1578 generator contains logic to activate the event frame when the analysis function result is TRUE,  
1579 and to stop the event frame after the analysis function result is FALSE or after a related  
1580 element variable changes to a value indicating that the failure or fault has been resolved.

1581 **D.2.7.1. High Workcell Temperature**

1582 If the simulated workcell temperature increases above the value of 29.0 degrees Celsius, then  
1583 generate an alert by using the following command:

```
1584 R261 := if ('WorkcellTemperature'>= 29.0) then 1 else 0;
```

1585 **D.2.7.2. Inspection Failure**

1586 If the inspection station reports a failed inspection count greater than or equal to three, then  
1587 generate an alert by using the following command:

```
1588 Alarm := If('FailedInspectionCounter' >= 3) Then 1 Else 0;
```

1589 **D.2.7.3. Station Out-of-Sync**

1590 If any of the machining stations is not in the RUN mode while the workcell is in the RUN  
1591 state, then generate an alert by using the following commands:

```
1592 S1State := '.\Elements[@Name=Station 1]|State';  
1593 S2State := '.\Elements[@Name=Station 2]|State';  
1594 S3State := '.\Elements[@Name=Station 3]|State';  
1595 S4State := '.\Elements[@Name=Station 4]|State';  
1596  
1597 WCState := If(TimeEq('WorkcellState','*-5s','*', "RUN")>=5)  
1598 Then "RUN" Else "Starting";  
1599 StationModes := if (S1State = "STOPPED" Or S2State = "STOPPED"  
1600 OR  
1601 S3State = "STOPPED" Or S4State = "STOPPED")  
1602 Then 1 Else 0;  
1603 Alarm := if (StationModes = 1 And WCState = "RUN") Then 1 Else  
1604 0;
```

1605 **D.2.8. Machining Station Asset Template Analysis Functions**

1606 The analysis functions provided in the following subsections were created to generate alerts  
1607 in the machining station asset template when their respective anomalous events are detected.  
1608 For the sake of brevity, the event-frame generation code is not shown. As previously  
1609 mentioned, in general, the typical event-frame generator contains logic to activate the event  
1610 frame when the analysis function result is TRUE, and to stop the event frame after the analysis  
1611 function result is FALSE or after a related element variable changes to a value indicating that  
1612 the failure or fault has been resolved.

1613    **D.2.8.1. High Trouble Call Count**

1614    Two analysis functions were created for this alert. First, determine if the machining station is  
1615    in the TROUBLE state by using the following command:

```
1616    Trouble := if ('State' = "TROUBLE" AND ((PrevVal('State', '*-  
1617    1s') = "TROUBLE") = False)) THEN "TROUBLE" ELSE NoOutput();
```

1618    If the machining station has entered the TROUBLE state, then count this event. If the number  
1619    of times that the machining station has entered the TROUBLE state in the previous  
1620    10 minutes is greater than or equal to five, then generate an alert by using the following  
1621    command:

```
1622    TroubleCount := If (EventCount('Alarm-TroubleCounterEvent', '*-  
1623    10m', '*') >= 5) Then 1 Else 0;  
1624    Variable1 := 'State';
```

1625    **D.2.8.2. Robot Proximity Fault**

1626    If the machining station is in the RUN mode and a robot proximity message has not been  
1627    received within the previous two minutes, then generate an alert by using the following  
1628    command:

```
1629    Alarm := If (('Mode' = "RUN") And (PrevVal('Mode', '*-2m') =  
1630    "RUN") And (TagMax(';RobotProximity', '*-2m', '*') = 0)) then 1  
1631    else 0;
```

1632    **D.2.8.3. Station Door Fault**

1633    If the machining station is in the ACTIVE state and the door is not closed, then generate an  
1634    alert by using the following command:

```
1635    Door_Open_Alarm := if (TimeEq('State', '*-2s', '*', "ACTIVE") >= 2  
1636    And TimeEq('Door State', '*-2s', '*', "CLOSED") < 1) Then 1 ELSE 0;  
1637    Variable1 := TimeEq('Door State', '*-2s', '*', "CLOSED");
```

1638    **D.2.8.4. Station Mode Error**

1639    If the register value for the machining station mode (as written by the PLC) is not within the  
1640    valid range of values (0 to 1), then generate an alert by using the following command:

```
1641    Alarm := If ('RawMode' < 0 OR 'RawMode' > 1) Then 1 Else 0;
```

1642 **D.2.8.5. Station State Error**

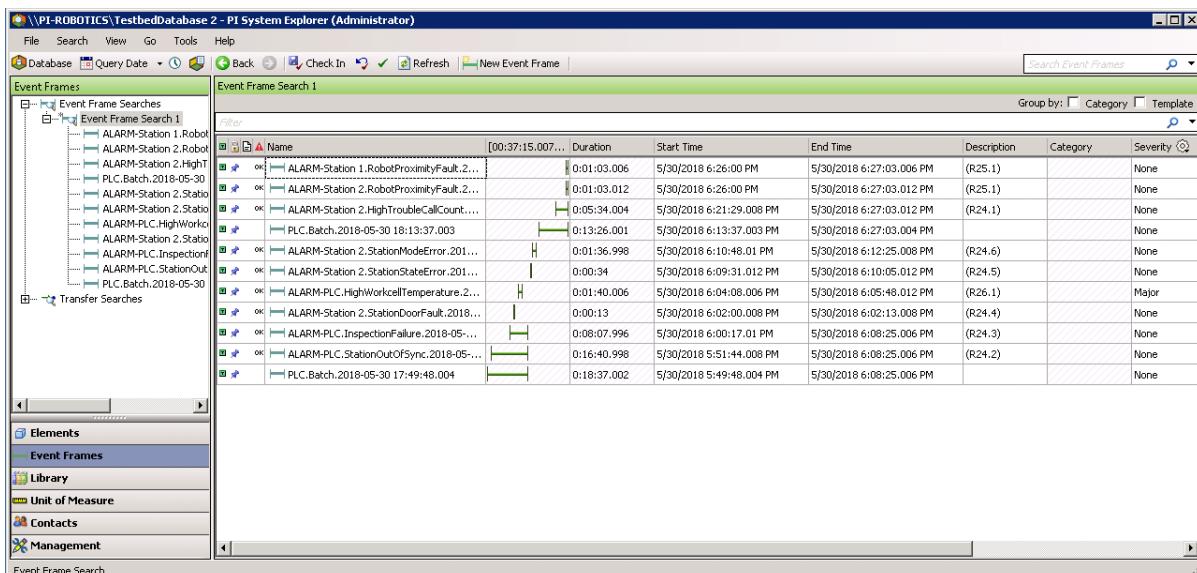
1643 If the register value for the machining station state (as reported by the machining station) is  
1644 not within the valid range of values (0 to 5), then generate an alert by using the following  
1645 command:

```
1646 Alarm := If('RawState' < 0 OR 'RawState' > 5) Then 1 Else 0;
```

1647 **D.2.9. Viewing and Acknowledging Alerts**

1648 The PI System Explorer was used to view and acknowledge alerts (event frames) generated  
1649 by the analyses templates. An example of the alerts is shown in Figure D-6, showing all of  
1650 the alerts generated by the anomalies during the execution of the anomaly scenarios.

1651 **Figure D-6 PI System Explorer Interface Showing an Example of Alerts Displayed to the**  
1652 **Operator for Acknowledgment, as Used During Anomaly Scenario Execution**



1653

1654 **D.3. Anomaly Scenarios**

1655 The historian/sensor-based anomaly detection method was demonstrated for the scenarios  
1656 detailed in the following subsections. Each scenario includes a description of the anomaly, a  
1657 detailed description of how each demonstration event was conducted in the Cybersecurity for  
1658 Smart Manufacturing Systems environment, and the observed results.

1659 The anomalies listed below demonstrate the fusion of cybersecurity and manufacturing  
1660 activities into a cohesive operation for detecting operational/maintenance issues and for  
1661 potentially identifying issues caused by cybersecurity incidents. In-depth knowledge of the  
1662 manufacturing system enables engineers to design PI System analysis functions to monitor  
1663 and alert when anomalous events occur, and to track trends of anomalies over extended  
1664 periods of time. With proper communication between operators and cybersecurity personnel,  
1665 anomalous manufacturing process events can be analyzed to determine if they could have  
1666 been caused by a cybersecurity incident and could have been mitigated.

1667 **D.3.1. Frequency Increase of Trouble Calls from a Machining Station**

1668 Trouble calls are automatically generated by a machining station when it detects an anomaly  
1669 during manufacturing operations (e.g., broken tooling, coolant failure).

1670 This anomaly was executed on the CRS. The machining station logic for Station 2 contained  
1671 a register that enabled trouble calls to be initiated on demand, generating the anomaly. This  
1672 register was set using a menu option on the human-machine interface (HMI). When enabled,  
1673 the machining station would enter the TROUBLE state after each part was placed in the  
1674 machine, and would be automatically cleared after eight seconds had elapsed.

Name	[00:31:42.003...]	Duration	Start Time
ALARM-Station 2.HighTroubleCallCount...	0:02:21.415	5/30/2018 6:21:29.008 PM	
PLC.Batch.2018-05-30 18:13:37.003	0:10:13.423	5/30/2018 6:13:37.003 PM	

1675 **D.3.2. Machining Station Shuts Down During Normal Workcell Operations**

1677 The workcell requires that all four machining stations are operational and in the RUN mode  
1678 while the workcell is in the RUN state.

1679 This anomaly was executed on the CRS. The machining station logic for Station 2 contained  
1680 a register that enabled a “forced shutdown” to be initiated, generating the anomaly. This  
1681 register was set using a menu option on the HMI. When enabled, the machining station  
1682 would enter the STOP mode while the rest of the workcell machines were operational.

Name	[00:01:57.003...]	Duration	Start Time
ALARM-PLC.StationOutOfSync.2018-05...	0:00:45.531	5/30/2018 5:51:44.008 PM	
PLC.Batch.2018-05-30 17:49:48.004	0:02:41.536	5/30/2018 5:49:48.004 PM	

1683 **D.3.3. Inspection Station Rejects All Parts Leaving the Workcell**

1685 The quantity of good and bad parts exiting the inspection station is counted by the  
1686 supervisory PLC. An increase in the number of rejected parts indicates that the workcell  
1687 should be inspected by an operator to determine the cause.

1688 This anomaly was executed on the CRS. The station logic for Station 4 contained a register  
1689 that enabled the “inspection failure of all parts” anomaly. This register was set using a menu  
1690 option on the HMI. When enabled, the inspection station would report a failed result for  
1691 every inspection performed until the anomaly was disabled.

Name	[00:10:30.005...]	Duration	Start Time
ALARM-PLC.InspectionFailure.2018-05...	0:00:43.048	5/30/2018 6:00:17.01 PM	

1693 **D.3.4. Machining Station Door Sensor Fails**

1694 The unsafe condition that this sensor failure can cause warrants investigation by an operator.  
1695 Substantial damage can occur to both the machining station and robots if this sensor failure is  
1696 not detected. This anomaly could be a goal for an attacker who has the intent to cause  
1697 production disruption or financial loss through equipment damage.

1698 This anomaly was executed on the CRS. The machining station has a simulated door that  
1699 must open and close to allow the robot to have access into the machine for placing raw  
1700 material and removing finished parts. The machining station logic for Station 2 contained a  
1701 register that enabled the door-sensor failure anomaly. This register was set using a menu  
1702 option on the HMI. When enabled, the failure of this sensor caused the machining station to  
1703 report that the door was always “OPEN.”

Name	[00:12:13.003...]	Duration	Start Time
ALARM-Station 2.StationDoorFault.2018...	0:00:10.492	5/30/2018 6:02:00.008 PM	

1704 **D.3.5. Abnormal Process Variable Data Is Transmitted to the PLC**

1705 Two-way communication occurs between the supervisory PLC and the machining station  
1706 during normal operations. If a process variable trends outside the known operational range,  
1707 then this anomaly should be reported.

1708 This anomaly was executed on the CRS. Each machining station contains a Modbus TCP  
1709 server for communicating operational information to, and receiving commands from, the  
1710 supervisory PLC. The machining station logic for Station 2 contained a register that enabled  
1711 specific operational information to be corrupted before it was transmitted to the PLC. This  
1712 register was set using a menu option on the HMI.

Name	[00:19:44.007...]	Duration	Start Time
ALARM-Station 2.StationStateError.201...	0:00:36.826	5/30/2018 6:09:31.012 PM	

1714 **D.3.6. Abnormal Process Variable Data Is Transmitted to a Machining Station**

1715 As previously mentioned, two-way communication occurs between the supervisory PLC and  
1716 the machining station during normal operations. If a process variable trends outside the  
1717 known operational range, then this anomaly should be reported.

1718 This anomaly was executed on the CRS. The supervisory PLC contains a Modbus TCP client  
1719 for communicating commands to, and receiving operational information from, the machining  
1720 stations. The supervisory PLC contained a register that enabled specific commands to be  
1721 corrupted before they were transmitted to the machining stations. This register was set using  
1722 a menu option on the HMI.

Name	[00:21:01.005...]	Duration	Start Time
ALARM-Station 2.StationModeError.201...	0:00:42.732	5/30/2018 6:10:48.01 PM	

1725 **D.3.7. Robots Fail to Send Required Sensor Data to a Machining Station**

1726 As previously mentioned, the unsafe condition that this sensor failure can cause warrants  
1727 investigation by an operator. Substantial damage can occur to both the machining station and  
1728 robots if this sensor failure is not detected. This anomaly could be a goal for an attacker who  
1729 intends to cause production disruption or financial loss through equipment damage.

1730 This anomaly was executed on the CRS. The machining station has a simulated door that  
1731 must open and close to allow the robot access into the machine for placing raw material and  
1732 removing finished parts. The two robots report their locations (via Modbus TCP) to the  
1733 machining stations so that they do not attempt to close the door while the robot is still  
1734 operating within the machine. Robot Controller 1 contains a configuration option to disable  
1735 this reporting, resulting in Stations 1 and 2 not receiving robot location information. This  
1736 configuration option was used to generate the anomaly.

Name	[00:36:12.995...]	Duration	Start Time
ALARM-Station 1.RobotProximityFault.2...	0:00:31.083	5/30/2018 6:26:00 PM	
ALARM-Station 2.RobotProximityFault.2...	0:00:31.086	5/30/2018 6:26:00 PM	

1737

**D.3.8. Workcell Temperature Increases Above a Specified Threshold**

1739 Process variables that impact the output quality of the workcell must be monitored for  
1740 deviation from expected values. The temperature of the workcell increases during normal  
1741 operations and must be properly cooled to maintain quality; therefore, the workcell  
1742 temperature is monitored.

1743 This anomaly was executed on the CRS. The workcell contained a simulated temperature  
1744 sensor, which was used to “monitor” the temperature within the workcell. The temperature  
1745 was then displayed to the operator, on the HMI. The workcell temperature would increase to  
1746 an expected value while the workcell was operational and would decrease to room  
1747 temperature when the system was shut down. During anomalous conditions, the temperature  
1748 would increase beyond a threshold, causing all parts produced during that period to be  
1749 scrapped.

1750 The temperature sensor was simulated by the PLC. The anomalous temperature increase was  
1751 enabled by a register within the PLC and was set using a menu option on the HMI.

Name	[00:14:21.001...]	Duration	Start Time
ALARM-PLC.HighWorkcellTemperature.2...	0:00:33.602	5/30/2018 6:04:08.006 PM	

1752

1753 **Appendix E. Acronyms and Abbreviations**

<b>24/7</b>	24 Hours a Day, Seven Days a Week
<b>AF</b>	Asset Framework
<b>BAD</b>	Behavioral Anomaly Detection
<b>CPU</b>	Central Processing Unit
<b>CRS</b>	Collaborative Robotic System
<b>CSMS</b>	Cybersecurity for Smart Manufacturing Systems
<b>CSV</b>	Comma-Separated Values
<b>CybersecVM</b>	Cybersecurity Virtual Machine
<b>DA</b>	Data Access
<b>DCOM</b>	Distributed Component Object Model
<b>DMZ</b>	Demilitarized Zone
<b>DNS</b>	Domain Name System
<b>DoS</b>	Denial of Service
<b>EICAR</b>	European Institute for Computer Antivirus Research
<b>EL</b>	Engineering Laboratory
<b>FTP</b>	File Transfer Protocol
<b>GB</b>	Gigabyte(s)
<b>GUI</b>	Graphical User Interface
<b>HMI</b>	Human-Machine Interface
<b>HTTP</b>	Hypertext Transfer Protocol
<b>ICMP</b>	Internet Control Message Protocol
<b>ICS</b>	Industrial Control System
<b>ID</b>	Identifier
<b>IDS</b>	Intrusion Detection System
<b>IP</b>	Internet Protocol
<b>IPC</b>	Industrial Personal Computer
<b>IT</b>	Information Technology
<b>LAN</b>	Local Area Network

<b>LTS</b>	Long-Term Support
<b>M</b>	Megabyte(s)
<b>MAC</b>	Media Access Control
<b>NCCoE</b>	National Cybersecurity Center of Excellence
<b>NIC</b>	Network Interface Card
<b>NIST</b>	National Institute of Standards and Technology
<b>NISTIR</b>	National Institute of Standards and Technology Interagency Report
<b>NTP</b>	Network Time Protocol
<b>OPC</b>	Object Linking and Embedding for Process Control
<b>OS</b>	Operating System
<b>OT</b>	Operational Technology
<b>PCS</b>	Process Control System
<b>PDF</b>	Portable Document File
<b>PHP</b>	Hypertext Preprocessor
<b>PI</b>	Process Information
<b>PLC</b>	Programmable Logic Controller
<b>ROS</b>	Robot Operating System
<b>SCADA</b>	Supervisory Control and Data Acquisition
<b>SIEM</b>	Security Information and Event Management
<b>SMT</b>	System Management Tools
<b>SNTP</b>	Simple Network Time Protocol
<b>SP</b>	Special Publication
<b>SPAN</b>	Switch Port Analyzer
<b>SSH</b>	Secure Shell
<b>TCP</b>	Transmission Control Protocol
<b>TE</b>	Tennessee Eastman
<b>UDP</b>	User Datagram Protocol
<b>URI</b>	Uniform Resource Identifier
<b>URL</b>	Uniform Resource Locator

<b>USB</b>	Universal Serial Bus
<b>VLAN</b>	Virtual Local Area Network
<b>VM</b>	Virtual Machine
<b>XAE</b>	eXtended Automation Engineering
<b>XLSX</b>	Microsoft Excel Workbook File

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