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*IABSRI's INPUT TO THE COMMISSION ON ENHANCING NATIONAL CYBERSECURITY

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"C2, CYBER, AND TRUST"

Theoretical Model for Cybersecurity: Using Socially-Aware Purposeful Agent and Reflexive Game Theory

Suggested Topics: Agile C2 Security; Modeling and Simulation; Concepts, Theory, and Policy

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ABSTRACT

Using the socially-aware purposeful agent, the new term coined by the author to replace the previous term purposeful agent, and the Reflexive Game Theory (RGT), this paper discusses the framework for constructing a theoretical model for cybersecurity. The paper uses the RGT to initially model the socially-aware purposeful agent, as a group of one socially-aware purposeful agent or elementary socially-aware purposeful agent that resides within the endpoint's internal operating environment. Unlike the traditional agent, the socially-aware purposeful agent has cognitive capabilities which permit the socially-aware purposeful agent to create a mental image or situational awareness of a threat object in the endpoint device's internal operating environment. Within the context of the RGT, the behavior of an elementary socially-aware purposeful agent is in the state of free choice. Upon realizing the threat object to be a malware, the socially-aware purposeful agent dynamically changes its behavior to be in conflict with the cyber hacker that launched the code. In terms of the RGT, we now have an interaction between two socially-aware purposeful agents, in conflict. A graph is then constructed for the two interacting socially-aware purposeful agents, in conflict. The graph is then decomposed to create the polynomial, depicting the analytical notation of the graph. A diagonal form is then established for the polynomial. Using the influences of the cyber hacker on the subconscious and conscious domains of the socially-aware purposeful agent, the subsets of actions to deal with the malware can now be predicted. The socially-aware purposeful agent can choose any of the predicted actions and realize any non-empty realizable subsets of the chosen set of actions. Four examples are given to demonstrate the theoretical model for cybersecurity. Furthermore, the framework borrows from pi-calculus to model interaction as the basis for information sharing among DoD System-of-Systems to mitigate cybersecurity risks.

INTRODUCTION

As cyber security has become serious threats to physical security system components or endpoint devices and current cyber security measures are inadequate to mitigate such threats, a critical need exists for a formal development of modeling the behavior of new agents with cognitive capabilities, for addressing the cyber security threats. An example of such new agents is the emerging socially-aware purposeful agent that not only can make a decision to perform some cybersecurity actions but also can interact with a cyber hacker and an instrument, e.g., a malware, which a cyber hacker uses to attack the physical security system components or endpoint devices. Because of its cognitive capabilities, the socially-aware purposeful agent can reason like a human to decide which set of the chosen cyber security actions to use for defeating a cyber threat. We define an instrument as an object which an individual or system uses to co-produce the outcome of an individual's or system's action [Ackoff et al. 2006]. Thus, a malware is an object which a cyber hacker, who is also a socially-aware purposeful agent, uses to co-produce the outcome, e.g., malware infection of a physical security system component or an endpoint device, of a cyber

hacker's action. In this case, the cyber hacker's action is attacking a user's endpoint device. We should emphasize that the instrument does not have the reasoning capability or the cognitive capability as the socially-aware purposeful agent (cyber hacker). According to Lefebvre (through private communication with Lefebvre [Nyamekye and Lefebvre, October 17, 2013]), a socially-aware purposeful agent can be an inanimate or animate subject, with a cognitive capability. Lefebvre also emphasizes that a subject, e.g., a Warfighter, a country, can be anything to which our attention is directed [Lefebvre 2010]. In this paper, we will focus our attention on cybersecurity modeling in endpoint devices. Future publications will focus on cybersecurity modeling in network systems.

To understand what we mean by modeling the behavior of a socially-aware purposeful agent that can reason like a human to decide which set of the chosen cyber security actions to use to defeat a cyber-threat, let us use "a strategic corporal" as an example, in dealing with insurgents, in irregular warfare (IW). A direct excerpt from Wikipedia [Wikipedia] explains "strategic corporal" as follows: *the **Three Block War** is a concept described by U.S. Marine General Charles Krulak in the late 1990s to illustrate the complex spectrum of challenges likely to be faced by soldiers on the modern battlefield. In Krulak's example, soldiers may be required to conduct a full-scale military action, peacekeeping operations and humanitarian aid within the space of three contiguous city blocks. The thrust of the concept is that modern militaries must be trained to operate in all three conditions simultaneously, and that to do so, leadership training at the lowest levels needs to be high. The latter condition caused Krulak to invoke what he called "strategic corporals"; low-level unit leaders able to take independent action and make major decisions*. Here the strategic corporal is the socially-aware purposeful agent and the insurgent is the cyber hacker. We can make an analogy between the operating environment, which may include the local tribesmen, tribal leaders, the villagers, of the "strategic corporal" and the operating environment, which may include the operating system, processors, application programs, etc., within the endpoint device's security system components. The "strategic corporal" has the responsibility to make a tactical choice or decision as a commander in one instance of attacking an enemy (insurgent), which in our cyber analogy, the cyber hacker's instrument (malware), and in another instance the "strategic corporal" may play the role of a local tribal leader, e.g., resolving tribal disputes among the indigenous people. The behavior of a strategic corporal, in playing the role of a local tribal leader in resolving tribal disputes among the indigenous people, is similar in concept to the behavior of a socially-aware purposeful agent, for example, interacting with new updates of software applications on the endpoint devices, to ensure that such new updates come from trusted sources. Thus, the socially-aware purposeful agent must have the cognitive capability to distinguish between the enemy (malware) and the friendly systems (trusted software applications), just as the strategic corporal can distinguish between the enemy (insurgent) and the local friendly indigenous people in the villages. We will later discuss socially-aware purposeful agent in details, within the context of an elementary subject and non-elementary subject [Nyamekye June 8, 2015], respectively.

While much literature exists on the two most popular anti-virus technologies, namely; virus scanners and integrity checkers, for detecting and preventing damage from computer viruses, very few publications exist on the behavior blockers, for detecting and eliminating viruses in endpoint devices. A brief overview of each technology is essential before subsequent discussions.

A virus scanner examines the contents of each file that can carry executable instructions, e.g., ".exe", ".bat", ".com", ".vbs", ".scr", etc. The virus scanner searches each potential file for certain "search strings" which are present in known viruses [Auburn University]. Using a variety of search techniques, e.g., fuzzy search, a virus scanner compares the executable instructions with the known executable instructions and if a match is found, it will eliminate the virus [Auburn University]. Since scanners use a database of known viruses, unknown viruses can easily escape detection [Auburn University]. More importantly, minor variants of known viruses can be missed.

An integrity checker creates a checksum for each executable file in a directory, and stores the results in a file [Auburn University]. Each time the integrity checker is run, it recomputes the checksum for each executable file and compares this value to the previously stored checksum [Auburn University]. If the values match, then the file is assumed to be clean. If the values do not match, the executable file has probably been infected by a virus [Auburn University]. Problems with integrity checking include the following [Auburn University]: a virus can modify checksum file, so when an integrity checker compares the computed checksum with checksum stored in the file, the integrity checker will ignore the file; a virus can delete the checksum file, thus with the checksum file deleted, there is no basis for determining previous checksums; a virus can encrypt checksum file, which has the same effect as deleting the checksum file; integrity checking only works for file infecting viruses, so, viruses that copy themselves to the hard disk (as many viruses do) will be ignored, since there is no checksum discrepancy.

A behavior blocker does not proactively search for certain "search strings" which are present in known viruses [Auburn University]. Rather, it monitors the system for suspicious activity. For example, a program "virus.exe" suddenly attempts to delete "all.mp3" files stored on the hard disk [Auburn University]. If the behavior blocker observes a suspicious activity, it will consult a list of rules to determine an appropriate action. For example, it may allow the program to continue performing the desired operation or it may terminate the program before the program attempts to perform the operations. If no appropriate rule is found, the behavior blocker will consult the user/administrator. A behavior blocker has many advantages [Auburn University]. Among them are: it is more resistant to unknown threats than virus scanning and integrity checking [Auburn University]; no need exists to download new virus definitions - the system does not necessarily require continual maintenance [Auburn University]. The disadvantages are namely: continuous monitoring of every aspect of system can greatly reduce system speed [Auburn University]; monitoring memory allocation, network access, file system access simultaneously is an expensive proposition [Auburn University]; many possible false positives can occur -- artificial intelligence

(AI) has simply not matured enough to correctly interpret every system action; system is not "bullet proof" -- new viruses may be able to perform actions that do not get flagged, but can still be used to execute payload [Auburn University]; new viruses may be able to emulate other programs installed on the system, fooling the system [Auburn University]. Despite these disadvantages, a behavior blocker offers great opportunities for future research in modeling anti-virus system. According to Auburn University [Auburn University], behavior blocking appears to be the future of anti-virus. In fact, model construction, for the socially-aware purposeful agent [Nyamekye 2013, Lefebvre and Nyamekye 2014] -- an emerging behavior blocker with cognitive capabilities --, is an example of such a research endeavor that can potentially fulfill such a research need.

Under the request by the Department of Defense for examining the theory and practice of cyber security, JASON Program Office at MITRE Corporation [JASON], conducted a study for identifying several subfields of computer science that might be specifically relevant to the science of cyber security. More importantly, JASON's efforts included evaluating whether some underlying fundamental principles that would make it possible to adopt a more scientific approach, existed to identify what was needed in creating a science of cyber security. Furthermore, JASON should recommend specific ways in which scientific methods could be applied for modeling cyber security. Among the subfields of computer science that JASON's study covered, were, namely: model checking, cryptography, randomization, and type theory [JASON]. For simplicity, we will use JASON to represent JASON Program Office at MITRE Corporation. A direct excerpt from JASON's study noted the following: *in model checking, one develops a specification of an algorithm and then attempts to validate various assertions about the correctness of that specification under the specific assumptions about the model. Cryptography, which examines communication in the presence of an adversary and in which the assumed power of that adversary must be clearly specified is viewed today as a rigorous field, and the approaches pursued in this area hold useful lessons for a future science of cyber-security. The use of obfuscation, in which one attempts to disguise or randomize the data paths and variables of a program, can help in constructing defenses against some common modes of attack. Type theory is any of several formal systems that can serve as alternatives to naive set theory and is also effective in reasoning about the security of programs. Game theoretic ideas will be useful in understanding how to prioritize cyber defense activities. Game theoretic approaches provide a framework for reasoning about which critical assets must be chosen for protection against cyber security risks*. The implication of JASON's study is that Game Theory provides the technical and scientific foundation for cybersecurity efforts! Though JASON's study was promising (and it is still so), it did not provide an in-depth discussion on how Game Theory could be employed to address cyber security.

Bruschi et al. [Bruschi et al. 2006] proposed a strategy for the detection of metamorphic malicious code inside a program P based on the comparison of the control flow graphs of P against the set of control flow graphs of known malware. They provided experimental data supporting the validity of their strategy. We should point out that a metamorphic malicious code exhibits a dynamic behavior instead of some static *properties* (e.g. fixed byte sequences or strangeness in the

executable header) [Bruschi et al. 2006]. Thus, malware detection, which is normally performed by pattern matching, within which malware detectors have a database of distinctive patterns (the signatures) of malicious code and they (malware detectors) look for the signatures in possibly infected systems, does not work well with metamorphic malicious codes [Bruschi et al. 2006]. In fact, virus scanners employ pattern matching techniques for detecting malicious codes.

In response to the cyber security threats to the U.S. critical infrastructure, President Obama signed an Executive Order (EO) 13636, "Improving Critical Infrastructure Cybersecurity," on February 12, 2013 [Whitehouse]. The Executive Order was designed to increase the level of core capabilities for U.S. critical infrastructure to manage cyber risk. It did this by focusing on three key areas: (1) information sharing, (2) privacy, and (3) the adoption of cybersecurity practices. The EO tasked the National Institute of Standards and Technology (NIST) to work with the private sector to identify existing voluntary consensus standards and industry best practices and build them into a Cybersecurity Framework. The NIST closely worked with the private sector to create the Cybersecurity Framework 1.0 [NIST]. The author of this technical paper contributed to the development of the CSF, through submission of comments to NIST [Nyamekye November 13, 2013; Nyamekye November 15, 2013]. The NIST Cybersecurity Framework contains three primary components: the Framework Core, the Framework Implementation Tiers, and the Framework Profiles. The Framework Core is a set of cybersecurity activities, desired outcomes, and applicable references that are common across critical infrastructure sectors. A direct excerpt from the Cybersecurity Framework will be helpful to provide an overview of it.

The Framework Core presents industry standards, guidelines, and practices in a manner that allows for communication of cybersecurity activities and outcomes across the organization from the executive level to the implementation/operations level. The Framework Core consists of five concurrent and continuous Functions—Identify, Protect, Detect, Respond, Recover. When considered together, these Functions provide a high-level, strategic view of the lifecycle of an organization's management of cybersecurity risk.

Framework Implementation Tiers provide context on how an organization views cybersecurity risk and the processes in place to manage that risk. Tiers describe the degree to which an organization's cybersecurity risk management practices exhibit the characteristics defined in the Framework (e.g., risk and threat aware, repeatable, and adaptive). The Tiers characterize an organization's practices over a range, from Partial (Tier 1) to Adaptive (Tier 4). These Tiers reflect a progression from informal, reactive responses to approaches that are agile and risk-informed. During the Tier selection process, an organization should consider its current risk management practices, threat environment, legal and regulatory requirements, business/mission objectives, and organizational constraints.

The Framework Profile represents the outcomes based on business needs that an organization has selected from the Framework Categories and Subcategories. The Profile can be characterized as

the alignment of standards, guidelines, and practices to the Framework Core in a particular implementation scenario. Profiles can be used to identify opportunities for improving cybersecurity posture by comparing a "Current" Profile (the "as is" state) with a "Target" Profile (the "to be" state). To develop a Profile, an organization can review all of the Categories and Subcategories and, based on business drivers and a risk assessment, determine which are most important; they can add Categories and Subcategories as needed to address the organization's risks. The Current Profile can then be used to support prioritization and measurement of progress toward the Target Profile while factoring in other business needs including cost-effectiveness and innovation. Profiles can be used to conduct self-assessments and communicate within an organization or between organizations. The Cybersecurity Framework not only provides an excellent common language to standardize the approach for addressing cybersecurity concerns, but also it provides the foundation on which the cybersecurity risks mitigation community must think about in creating a *proactive methodology* -- *Framework Implementation Tier 4* -- for addressing cybersecurity threats before they even occur. A behavior blocker naturally fits into this new paradigm. Most importantly, the author's paper addresses such a critical issue on the *proactive methodology* for mitigating cyber threats. We will later discuss how this paper fulfills this issue and agility as noted before. Today, many of the antivirus solutions react to cybersecurity threats after they occur. Thus, it is fitting to emphasize the importance of this paper in augmenting the NIST's Cybersecurity Framework 1.0, provided in Appendix A.

The recent publication of Lefebvre and Nyamekye [Lefebvre and Nyamekye 2014] has discussed how we can use RGT to model terrorists' activity. Both authors' work provides some insightful ideas into modeling the cyber security threats in endpoint devices.

The organization of this paper is as follows. In the subsequent sections we will first discuss an overview of RGT, and purposeful individuals and socially-aware purposeful agents, followed by the mathematical model of RGT in *choice or decision making* of a socially-aware purposeful agent. Based on the recent author's work [Nyamekye June 8, 2015], we will discuss a socially-aware purposeful that can behave as an elementary subject (with new features established as an extension of RGT), and as a non-elementary subject, within the context of elementary and non-elementary subjects, respectively, as previously noted. Borrowing from the previous work of Lefebvre [Lefebvre 1977] we will provide the theoretical framework for *situational awareness*. Then four examples will be given to demonstrate how we can use RGT to model cybersecurity threats. Conclusions will then follow. Appendix B will borrow from pi-calculus to model *interaction* as the basis for information sharing among DoD System-of-Systems to mitigate cybersecurity risks.

OVERVIEW OF REFLEXIVE GAME THEORY (RGT), PURPOSEFUL INDIVIDUALS AND SOCIALLY-AWARE PURPOSEFUL AGENTS

From the viewpoint of the classical game theory, decision making involves two types of theories, namely: descriptive theory and prescriptive theory. The descriptive theory is about a choice

prediction of a player [Lefebvre 2010], and the prescriptive theory is about the choices the player must make – choice selection from the choice prediction. To minimize the losses of a player, the classical game theory employs max-min decision function for both theories. A major issue with the classical game theory is that a player is inclined to an irrational risk in making a decision – from faulty reasoning process [Lefebvre 2010]. Consequently, we cannot use the classical game theory when we want to minimize risk in choice or decision making. Particularly in cybersecurity modeling, where much uncertainty (e.g., a deceitful cyber hacker's instrument in the endpoint's internal operating environment) could lead to irrational risk in the socially-aware purposeful agent choice or decision-making, -- inadvertently deleting a software application from a trusted and known source -- the classical game theory is inappropriate for decision-making. More importantly, the classical game theory does not account for the cognitive system of the socially-aware purposeful agent – e.g. the socially-aware purposeful agent -- in decision making. The RGT addresses such deficiencies in choice or decision making. The goal of RGT is to predict the individual choice made by a socially-aware purposeful agent belonging to a group [Lefebvre 2010]. Also, the RGT can predict the influences of other socially-aware purposeful agents in a group on another socially-aware purposeful agent to make a particular choice [Lefebvre 2010]. We call such an extension of the RGT, reflexive control [Lefebvre 2010]. This paper will not address reflexive control. Please note that a socially-aware purposeful agent can represent single individuals or different types of organizations, e.g., military units, political parties, and even states [Lefebvre 2010]. Though this paper will not deal with reflexive control, the concept of reflexive control is very intriguing and deserves attention, especially for cybersecurity modeling. For example, in cybersecurity modeling, if the socially-aware purposeful agent can find the Internet Protocol (IP) address of the cyber hacker's endpoint device, the socially-aware purposeful agent can send a deceptive message to the cyber hacker to purposely influence the cyber hacker to make a decision that would benefit the objectives of the socially-aware purposeful agent. The idea here is to create a mental model of the cyber hacker and thereby use it to influence the cyber hacker's future actions. The author's future publications will address reflexive control, in cybersecurity modeling. The term socially-aware purposeful agent draws from the purposeful individual or system [Ackoff et al. 2006; Lefebvre 2010]. A brief overview of a purposeful individual, system or a socially-aware purposeful agent is essential, before subsequent discussions.

A purposeful individual or system [e.g., a cyber hacker or system (e.g., a weapon system)] is one that can not only change its behavior to pursue the same goal -- as conditions in the operating environment change -- but also a purposeful individual or system is one that can choose its own goals and the means by which to pursue the goals [Ackoff et al. 2006]. *A purposeful individual or system thus displays will* [Ackoff et al. 2006.] Please note that a purposeful individual or system can also learn and adapt itself to uncertainties in its environment [Ackoff et al. 2006]. More importantly, the environment of the individual or system cannot choose the goals for the purposeful individual or system! This statement implies that a purposeful individual or system is a PROACTIVE system (as opposed to a simple "Pavlovian" system that just reacts to changes in its surrounding environment, e.g., a virus scanner). Only humans or people are purposeful individuals or systems! Thus, Nano-devices, artificially intelligent robots, etc., are not purposeful systems. They emulate purposeful systems. Ackoff et al. [Ackoff et al. 2006] call such systems, multi-goal-seeking individuals or systems. The users -- humans (e.g., the strategic corporal) -- of these systems set the goals! ***We define socially-aware purposeful agents to be agents that can set their own***

goals and they have the same cognitive capabilities closely resembling those demonstrated by humans. ***Contrary to the socially-aware purposeful agents, the traditional agents cannot set their own goals and they lack cognitive capabilities of humans*** [Nyamekye 2013; Lefebvre and Nyamekye 2014]. This is the fundamental difference between the traditional agent and the socially-aware purposeful agent. In fact, North and Macal [North and Macal 2007, Page 102] clearly articulate the *traditional agent* as follows: "*The fundamental features that make something a candidate to be modeled as a traditional agent are the capabilities of the component to make independent decisions, some type of goal to focus the decisions, and the ability of other components to tag or individually identify the component." Unlike the socially-aware purposeful agent that sets its own goals, the traditional agent must use the goal set by some individual or the user of the system being modeled*. We should emphasize that the term socially-aware purposeful agent replaces the author's previous term, purposeful agent [Nyamekye 2013; Lefebvre and Nyamekye 2014].

SOCIALLY-AWARE PURPOSEFUL AGENT: AS AN ELEMENTARY SUBJECT AND NON-ELEMENTARY SUBJECT, RESPECTIVELY

A theory must be logically completed [Lefebvre 2010]. For logical completeness, RGT must include a diagonal form consisting of one letter, Equation 1. We call this form an elementary subject. The elementary subject has the *freedom of choice* [Lefebvre 2010]. A dismounted Warfighter investigating the presence of a landmine on the battlefield, while the other members of the small unit search for the enemy on the battlefield, is an example of an elementary subject. We will later discuss the *freedom of choice*. Please note that such a dismounted Warfighter may not be temporarily interacting with the small unit, as he or she focuses his or her attention on the landmine. By logical completeness, we mean that Equation 1 should not include non-defined elements [Lefebvre 2010]. Because of this, the subject's choice cannot be predicted by an external observer [Lefebvre 2010]. To predict subjects' possible choices, RGT needs at least two subjects with their *relations* [Lefebvre 2010]. We will later discuss the *relations* among non-elementary subjects. We call such subjects non-elementary subjects [Lefebvre 2010]. When the dismounted Warfighter investigating the presence of a landmine on the battlefield changes from non-interaction to interaction with the small unit, he or she becomes a non-elementary subject. Borrowing from Lefebvre's work [Lefebvre 2010], we represent the theoretical model of a non-elementary subject by a diagonal form of the type shown in Equation 2a.

$$a = [a] \qquad \text{Equation 1}$$

$$\Phi = P^{W} \qquad \text{Equation 2a}$$

where P is the bottom-most polynomial of the diagonal form [Lefebvre 2010]; $W = A_1 * A_2 * \ldots * A_k$; $k \geq 2$; * either "**.**", or "**+**", and A_i diagonal forms representing the subject's images of self [Lefebvre 2010]. We should emphasize that W is the non-elementary subject's *integral image of*

the self [Lefebvre 2010], which in RGT consists of a collection in cooperation or conflict with one another [Lefebvre 2010]. For details about the *integral image of the self*, please refer to the previous publication of Lefebvre and Nyamekye [Lefebvre and Nyamekye 2014]. Most importantly, W is the result of the non-elementary subject's *mental choice*, in the subject's cognitive system [Lefebvre 2010]. This statement does not imply that an elementary does not have a cognitive system or a mental system. It simply means that W is the result of the *choice* made by the *integral image of self* – in the subject's mind -- for a non-elementary subject. Equation 2a is an exponential function [Lefebvre 2010], with P, the base and W, the exponent of the function, respectively. Equation 2a can be represented as Equation 2b. Lefebvre calls it a *reflexion function*.

$$\Phi = P + \bar{W} \qquad \text{Equation 2b}$$

Because of the importance of the elementary subject in cybersecurity modeling and more importantly in many situations on the battlefield, the author has recently extended the RGT to establish new features for an elementary subject (elementary socially-aware purposeful agent). Below is the direct excerpt from the author's work [Nyamekye June 8, 2015]:

Awareness: An elementary subject (elementary socially-aware purposeful agent) is aware of "something" [Ackoff et al. 2006] if he or she forms a "mental picture (image)" [Lefebvre 1977] of the "something". The elementary subject (elementary socially-aware purposeful agent) is said to have a situational awareness of the "something." The "something" may be an instrument [Ackoff et al. 2006], e.g., a landmine (on the battlefield), used by another elementary subject (elementary socially-aware purposeful agent) to coproduce some outcome of that elementary subject's (elementary socially-aware purposeful agent's) action [Ackoff et al. 2006] against the elementary subject (elementary socially-aware purposeful agent).

Understanding: An elementary subject (elementary socially-aware purposeful agent) understands the meaning of the mental picture (image) of the "something" if he or she influences [Lefebvre 1977] himself or herself that the "something" can produce a course of action [Ackoff et al. 2006] against him or her with desirable or undesirable outcome. The elementary subject (elementary socially-aware purposeful agent) is said to have self-influence [Lefebvre 1977]. That "something" may be an instrument used by another elementary subject (elementary socially-aware purposeful agent) to coproduce the outcome of that elementary subject's (socially-aware purposeful agent's) action.

Decision: An elementary subject (elementary socially-aware purposeful agent) has the freedom of choice [Lefebvre 1977], from which he or she can choose a realizable set of actions or an alternative [Lefebvre 1977]. The elementary subject (elementary socially-aware purposeful agent) is said to make a decision. Please note that while these extra features are extensions of RGT, they do not ensue from RGT. For simplicity, we will interchangeably use the term *an elementary socially-aware purposeful agent* with *an elementary subject*.

MATHEMATICAL MODEL OF REFLEXIVE GAME THEORY (RGT) FOR CHOICE OR DECISION MAKING

Conceptual Representation of a socially-aware purposeful agent

In RGT, we assume that a socially-aware purposeful agent can perform actions $\alpha 1, \alpha 2, \ldots, \alpha s, S \geq 1$ [Nyamekye 2013; Lefebvre 2010]. Such actions are initially defined, similar in concept to the actions initially defined for an *automaton* in pi-calculus [Milner 1999]. Also, we assume that the socially-aware purposeful agent can perform these actions both technically and morally [Nyamekye 2013; Lefebvre 2010]. According to Lefebvre, *the relation of preference on the set of actions is not given.* He defines a universal set, as a non-empty set of actions which can be represented as 1. Please note that an empty set contains no elements or actions. The set ***M*** of all subsets of the universal set, including an empty set, is the set of alternatives [Nyamekye 2013; Lefebvre 2010]. That is, each alternative is a subset of the universal set of actions. The socially-aware purposeful agent's action then consists of choosing an alternative from the set ***M*** and then "realizing" the "choice" [Lefebvre 2010]. When a socially-aware purposeful agent chooses an empty set, it means that the socially-aware purposeful agent refuses to choose any non-empty alternative. To distinguish between the "realization" and "choice", consider a universal set which consists of two sets [Nyamekye 2013; Lefebvre 2010]:

$\alpha 1$- turn left
$\alpha 2$- turn right

We represent the universal set as 1= $\{\alpha 1, \alpha 2\}$, and empty set as 0 = {}. Using the Boolean algebra, we can represent all the possible alternatives (set of actions) as:

1= $\{\alpha 1, \alpha 2\}$, $\{\alpha 1\}$, $\{\alpha 2\}$, 0 = {}

Please note that if the universal set consists of elements (actions), then we can always find the corresponding Boolean algebra, consisting of all the possible set of actions, including the empty set, from the relationship 2^Z (power set) [Lefebvre 2010]. Please note that the set ***M*** as previously noted includes not only the set of all subsets of the universal set, -- 4 in the above case --, but also the set ***M*** includes the Boolean operations "+", "**.**", "***negation***", and the relation "***greater or equal***". The choice of $\{\alpha 1\}$ means that the socially-aware purposeful agent can perform only action $\alpha 1$, and the choice of $\{\alpha 2\}$ means that the socially-aware purposeful agent can perform only action $\alpha 2$. Consider the alternative $\{\alpha 1, \alpha 2\}$. Since the socially-aware purposeful agent cannot perform actions $\alpha 1$(turn left) and (turn right) $\alpha 2$ at the same time, alternative $\{\alpha 1, \alpha 2\}$ is not realizable. However, the socially-aware purposeful agent can realize either subset $\{\alpha 1\}$ or subset $\{\alpha 2\}$ after socially-aware purposeful agent chooses alternative $\{\alpha 1, \alpha 2\}$. The socially-aware purposeful agent does nothing if the socially-aware purposeful agent chooses the empty set 0 = {}.

Choice or Decision Making Equation of a socially-aware purposeful agent

Equation 3 predicts the choices of a socially-aware purposeful agent. Equation 3 is the descriptive model we noted before.

$$X = AX + B\bar{X} \qquad \text{Equation 3}$$

where X, A, B ϵ(elements of) $\boldsymbol{M}$ and A and B do not depend on X [Lefebvre 2010]. Equation 3 has a solution if and only if Equation 4 is valid. The "+" represents the Boolean operator.

$$A \supseteq B \qquad \text{Equation 4}$$

Using Equations 3 and 4, we can find alternatives that the socially-aware purposeful agent can realize. The socially-aware purposeful agent then performs the set of actions, from the chosen alternatives. This last step is the prescriptive model. In RGT, a socially-aware purposeful agent can exhibit four states ***of behavior*** [Lefebvre 2010]: the socially-aware purposeful agent cannot make a choice or ***is in a state of frustration***; the socially-aware purposeful agent can have a freedom of choice or ***is in a state of free choice***; the socially-aware purposeful agent can ***only*** choose to do nothing or ***is in a passive state***; the socially-aware purposeful agent can choose to perform some action or ***is in an active state***.

MODELING SITUATIONAL AWARENESS

We will borrow from the pioneering work of Lefebvre [Lefebvre 1977] on the structure of awareness, to discuss *situational awareness*. Consider an elementary socially-aware purposeful agent which can be an inanimate or animate system, for example, a socially-aware purposeful agent, with a cognitive capability. As we noted before, an elementary socially-aware purposeful agent's choices of alternatives are known -- prescriptive model. Thus, the RGT does not apply for an elementary socially-aware purposeful agent. That is, RGT only applies to interaction between at least two socially-aware purposeful agents, as we previously discussed. Consider the strategic corporal in the rural area of the indigenous people in Afghanistan. At time $\boldsymbol{t0}$ the strategic corporal sees an object which resembles an improvised explosive device (IED) at a nearby place in the village. We should emphasize that the IED is an instrument which some insurgent (a socially-aware purposeful agent) has placed at the location. Let us suppose that at $\boldsymbol{t0}$ the strategic corporal has not yet formed an image within him or her. According to Lefebvre [Lefebvre 1977], we can represent the situation at $\boldsymbol{t0}$ by Equation 5.

$$\Omega 0 = T \qquad \text{Equation 5}$$

where T = represents the IED. At time $t1$, the strategic corporal forms a *mental picture (image)* of the IED. That is, he or she becomes aware that the IED could be a deadly object to him or her. According to Lefebvre, we can represent the situation at $\boldsymbol{t1}$ by Equation 6.

$$\Omega 1 = T + Tx \qquad \text{Equation 6}$$

where Tx = image of the IED within the strategic corporal. Equation 6 models the *situational awareness* of an elementary socially-aware purposeful agent -- the strategic corporal. We will

discuss awareness of a socially-aware purposeful agent in a group consisting of two socially-aware purposeful agents.

EXAMPLES

Example 1: A cyber hacker interacts with the supplier of a major retail company. The hacker sends a virtual instrument -- a malware, e.g., a Trojan -- to the supplier's desktop PC. The virtual instrument then steals the login credentials which the supplier uses to access the database of the retail company. Using another virtual instrument -- a malicious code -- and the stolen login credentials, the hacker successfully penetrates into the retail company's information system and steals massive personal data of the retailer's customers. For simplicity, we will create the cybersecurity model for the interaction between the cyber hacker and the supplier (user). The interaction, between the cyber hacker and the supplier, represents an example of a group consisting of two socially-aware purposeful agents -- the cyber hacker and the supplier or the user. Figure 1 shows the basic diagram of the interaction between the cyber hacker and user.

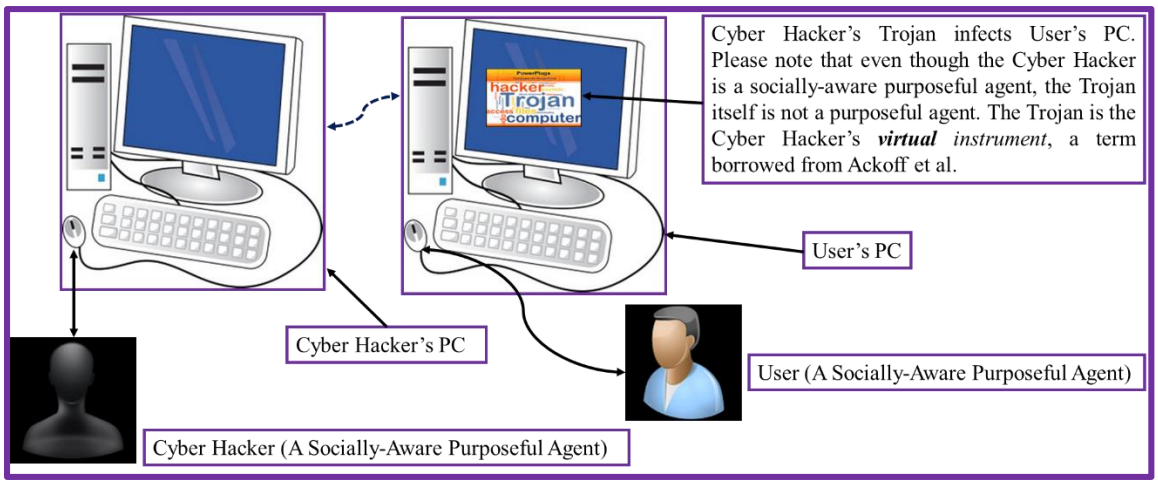

Figure 1. The Interaction between a Cyber Hacker and a User (Supplier).

In RGT, constructing a model begins with the definition of the socially-aware purposeful agents, which in this example are, namely: the cyber hacker and the user, in Figure 1. Also, the socially-aware purposeful agents define their ***set of actions***. The next step is the construction of the graph, Figure 2, which represents the relationships between the socially-aware purposeful agents. For example, a dotted line represents conflict, and a solid line represents cooperation, between any two socially-aware purposeful agents. Letter "a" stands for a victim (user). Letter "b" stands for the cyber hacker; b = 1 means b's influence to "a" is to allow penetration to a's system; b=0 means the absence of this influence.

Please notice that we have modeled the relationship between the cyber hacker and the user, as a cooperation. Typically, cyber hackers usually pretend to be nice folks whenever they infiltrate into the endpoint devices of users. That is, they pretend to be acquaintances of the users and thus, they

feel they are no threats to the users. We have assumed that the user has no antivirus application installed on his or her desktop PC. Even if an antivirus application exists, the cyber hacker's malicious code can conceal itself from detection -- metamorphic malware. For details about constructing the graph in RGT, please see the work of Lefebvre [Lefebvre 2010]. From the graph, Figure 2, we then construct the polynomial, Equation 7, which represents the analytical notation of the graph, where the "+", represents the Boolean operation for addition, and "**.**", represents the Boolean operation for multiplication [Lefebvre 2010]. Again, for details about the polynomial in RGT, please see the work of Lefebvre [Lefebvre 2010].

Figure 2. The Graph, Depicting Cooperation between the Cyber Hacker and the User.

$$[a].[b] \qquad \text{Equation 7}$$

The next step is to convert the polynomial into a diagonal form, Equation 8. The first part of the diagonal form represents the group's influence on the socially-aware purposeful agent, in making a choice or decision. The rest of the diagonal form represents the mental choice (from the cognitive system), W, in Equation 2, of the socially-aware purposeful agent. We can think of the diagonal form as an exponential function (Equation 2a), where the base of the exponential function is the same as the polynomial (Equation 7 or P in Equation 2a) and the exponent (same as W in Equation 2a) is the mental choice of the socially-aware purposeful agent, in decision-making. Again, for details about the diagonal form in RGT, please see the work of Lefebvre [Lefebvre 2010].

$$a = [a].[b]^{[a].[b]} \qquad \text{Equation 8}$$

In a cybersecurity threat where the cyber hacker manages to attack the user's endpoint device, -- with or without antivirus application --, we can model the situation as follows: a is not aware of b's influence; the values of b are different on the first and second tiers: b1 is a's subconscious image of b; b2 is a's conscious image of b. Substitution of b1 and b2 into Equation 8 yields Equation 9.

$$a = [a].[b1]^{[a].[b2]} \qquad \text{Equation 9}$$

During the cyber hacker's attack, the user subconsciously feels that strange signals in the desktop's operating system do not mean the existence of outside influence, but his or her conscious analysis shows that something is threatening the operating system's normal functioning: b1 = 0, b2 = 1. That is, the user is ***unaware*** of his or her subconscious level that his or her PC is being attacked. The user only becomes ***aware*** at his or her conscious level that his or her PC has been attacked. Substitution of the values of b1 and b2 into Equation 9 yields Equation 10.

$$a = [a].[0]^{[a].[1]}$$ Equation 10

Using the *reflexion function* [Lefebvre 2010], Equation 2b, we can then transform the diagonal form into the final analytical form, Equation 11, to obtain the generic choice equation for a.

$$a = [a].[0]^{[a].[1]} = 0 + \bar{a} = \bar{a}$$ Equation 11

Equation 11 says that "a" cannot make a choice. That is, the user is in a state of frustration -- cannot perform any action! The cyber hacker has used his or her virtual instrument -- malicious code, e.g., a Trojan -- to totally take control of the user's PC. More importantly, the hacker has already stolen the login credentials for penetrating into the retailer's information system!

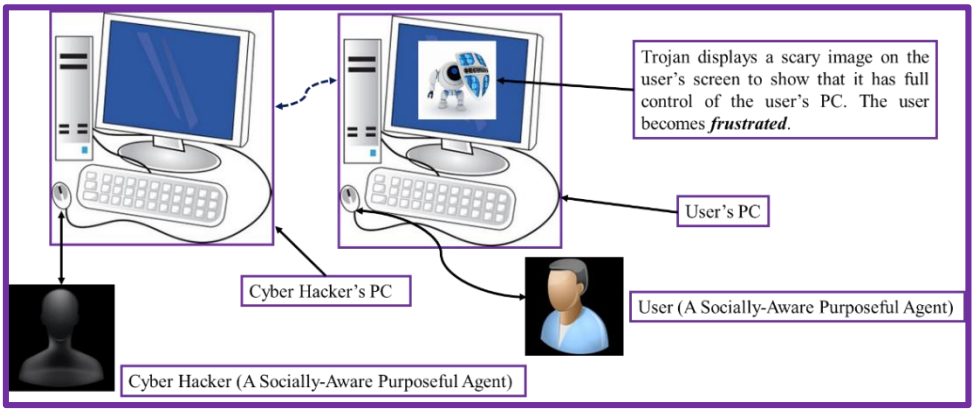

Figure 3. User's Frustration (Awareness) After Trojan Infects User's PC.

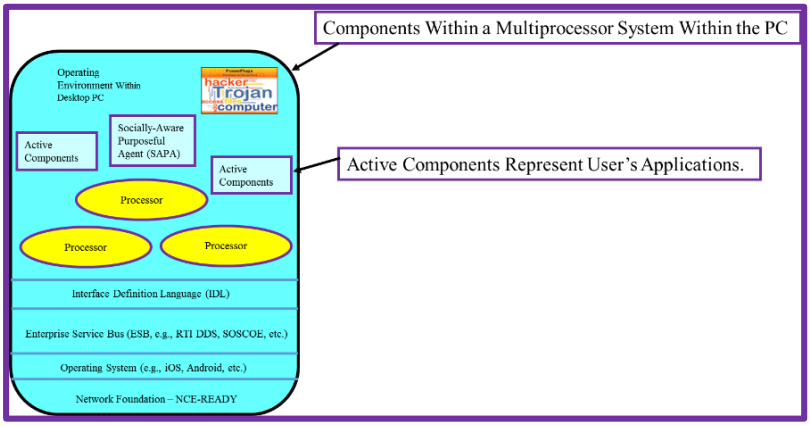

Figure 4. Multiprocessor System with Socially-Aware Purposeful Agent.

Figure 3 shows the user's frustration after the cyber hacker uses his or her virtual instrument, e.g., Trojan to infect the user's PC.

Example 2: Suppose we now explore building an emerging socially-aware purposeful agent or an emerging ***behavior blocker***, to address the cyber security threat in Example 1.

Figure 4 shows a new multiprocessor system that we have invented within the PC of the user. For simplicity, we have omitted the details of the new multiprocessor system. The active components represent the user's application programs. The multiprocessor system also contains a ***socially-aware purposeful agent***, which we have also invented to continuously monitor the system and to create ***a situational awareness*** (Equation 6) of any object it encounters. Then it takes remedial actions to destroy any malicious threat, e.g., Trojan. In this example, only one socially-aware purposeful agent or an elementary subject exists. As we noted before, RGT requires at least two socially-aware purposeful agents. However, we can use Equation 1 to represent the set of actions of the socially-aware purposeful agent. In this case, the socially-aware purposeful agent is ***in a state of free choice***.

$$a = [a] \qquad \text{Equation 1}$$

The implication of the socially-aware purposeful agent is that not only can it exhibit a dynamic behavior but it can choose its goals and a set of actions to fulfill the new goals. Thus, it can deal with any emerging cybersecurity threat, similar in concept to the strategic corporal dealing with a variety of emerging warfighting situations in irregular warfare (IW).

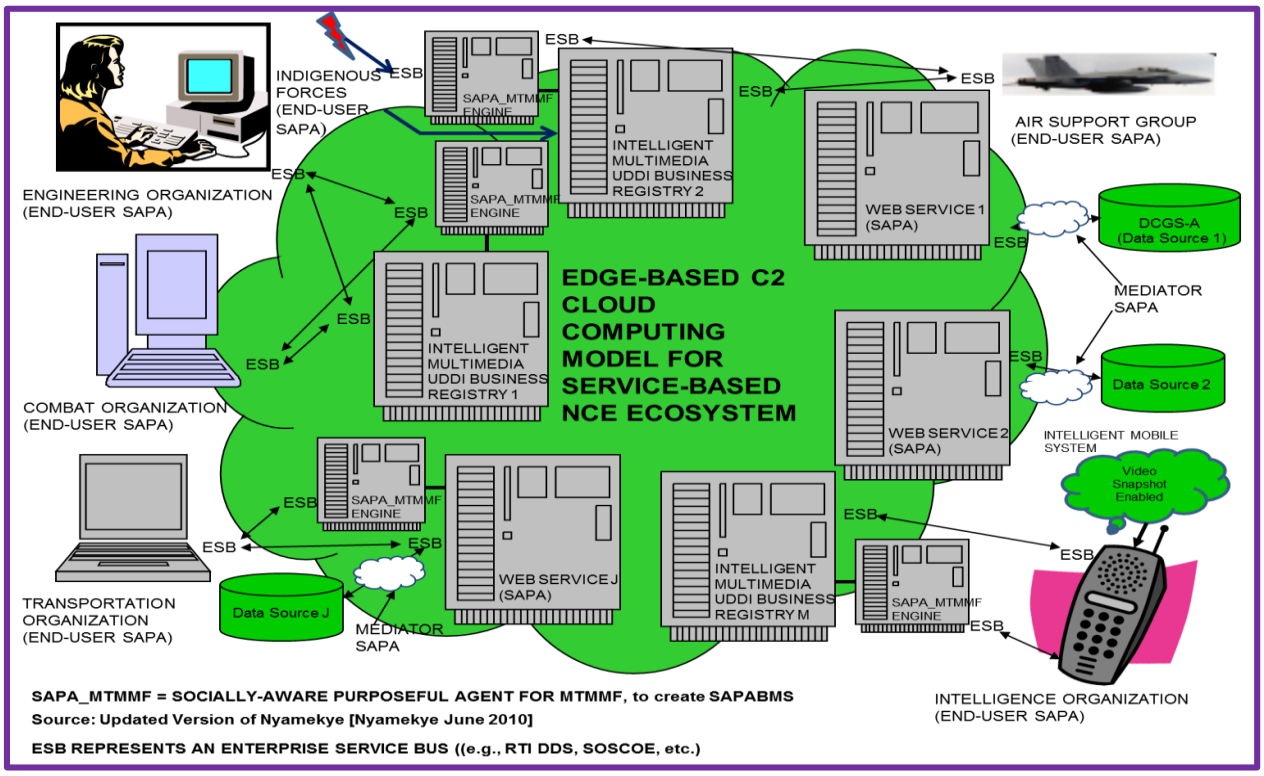

Figure 5. MTMMF SAPA-Based Modeling and Simulation (SAPABMS) C2 and Supporting System-of-Systems Architecture [Nyamekye 2010].

Example 3: To mitigate cybersecurity risks in a net-centric ecosystem for supporting the warfighters on the battlefield, we have extended our model by introducing a socially-aware purposeful agent in each endpoint device for the Multi-Threaded Missions and Means Framework (MTMMF) Socially-Aware Purposeful Agent-Based Modeling and Simulation (SAPABMS) Command and Control (C2) and the Supporting System-of-Systems Architecture. For details on the MTMMF and net-centric ecosystem for C2 and the Supporting SoS Architecture, please see the previous work of Nyamekye [Nyamekye 2010]. Figure 5 shows such architecture.

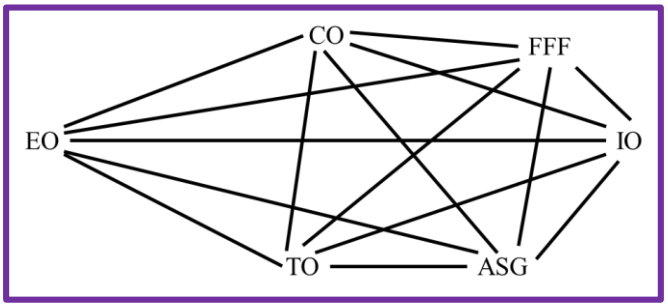

Figure 6. The Graph for Interaction among the Socially-Aware Purposeful Agents in Multi-Threaded Missions and Means Framework (MTMMF) Socially Aware Purposeful Agent-Based Modeling and Simulation (SAPABMS) Command and Control (C2) and the Supporting System-of-Systems Architecture [Nyamekye 2010].

The group consists of six socially-aware purposeful agents. They are represented as follows: Engineering Organization (EO), Combat Organization (CO), Transportation Organization (TO), Intelligence Organization (IO), Air Support Group (ASG), and Friendly Freedom Fighters (FFF) -- represented as one group. Cooperation exists among them. Figure 6 depicts the graph; each node corresponds to a socially-aware purposeful agent. The set of actions for each socially-aware purposeful agent includes: monitor system for suspicious activity, terminate the program for suspicious activity, destroy program with suspicious activity. Thus, the universal set of actions is 1 = {monitor system for suspicious activity, terminate the program for suspicious activity, destroy program with suspicious activity}. Each socially-aware purposeful agent influences each other to report any suspicious activity that each socially-aware purposeful agent encounters from any cyber security threat and the action the socially-aware purposeful agent takes to eliminate the threat to all socially-aware purposeful agents in the group. Equations 12 and 13 give the polynomial and the diagonal form, respectively.

$$[EO].[CO].[TO].[IO].[ASG].[FFF] \quad \text{Equation 12}$$

$$[EO].[CO].[TO].[IO].[ASG].FFF^{[EO].[CO].[TO].[IO].[ASG].[FFF]} \quad \text{Equation 13}$$

$$[EO].[CO].[TO].[IO].[ASG].FFF^{[EO].[CO].[TO].[IO].[ASG].[FFF]} = 1 \quad \text{Equation 14}$$

Transforming the diagonal form into a final analytical form (by applying the *reflexion function*, Equation 2b), yields Equation 14. Equation 14 says that all socially-aware purposeful agents are *superactive* agents [Lefebvre 2010]. That is, each socially-aware purposeful agent always chooses alternative 1 = {monitor system for suspicious activity, terminate the program for suspicious activity, destroy program with suspicious activity}. More importantly, each socially-aware purposeful agent cannot influence the behavior of other socially-aware purposeful agents, in the group. That is, no socially-aware purposeful agent's choice of action -- from the universal set of actions -- depends on any socially-aware purposeful agent's influence. At any state, the socially-aware purposeful agent can only choose and execute one action from the universal set. More importantly, each socially-aware purposeful agent can exhibit a dynamic behavior -- change its behavior depending on the cybersecurity threat -- at any state. The superactive behavior of a socially-aware purposeful agent is quite intriguing on cyber security threats because such a behavior implies that no master-slave relationship, -- which usually may slow down the decision a socially-aware purposeful agent must make in critical situations --, exists among the agents. Such a behavior of a superactive socially-aware purposeful agent is the thinking behind the behavior of a "strategic corporal" when dealing with insurgents' dynamic behaviors at the tactical level in irregular warfare (IW). The strategic corporal can call for air support if needed but he or she needs not wait for the commander to tell him or her what to do at the tactical level in attacking and defeating insurgents in IW.

Example 4: The elementary socially-aware purposeful agent dynamically changes its behavior to be in conflict with the cyber hacker after realizing from the ***situational awareness*** of the cyber hacker's instrument -- Trojan -- that the cyber hacker intends to inflict harm. The model is identical to Example 1 except that Figure 1 is slightly modified to depict the socially-aware purposeful agent, to monitor the Trojan on the PC screen of the user. Figure 7 shows the modified Figure 1.

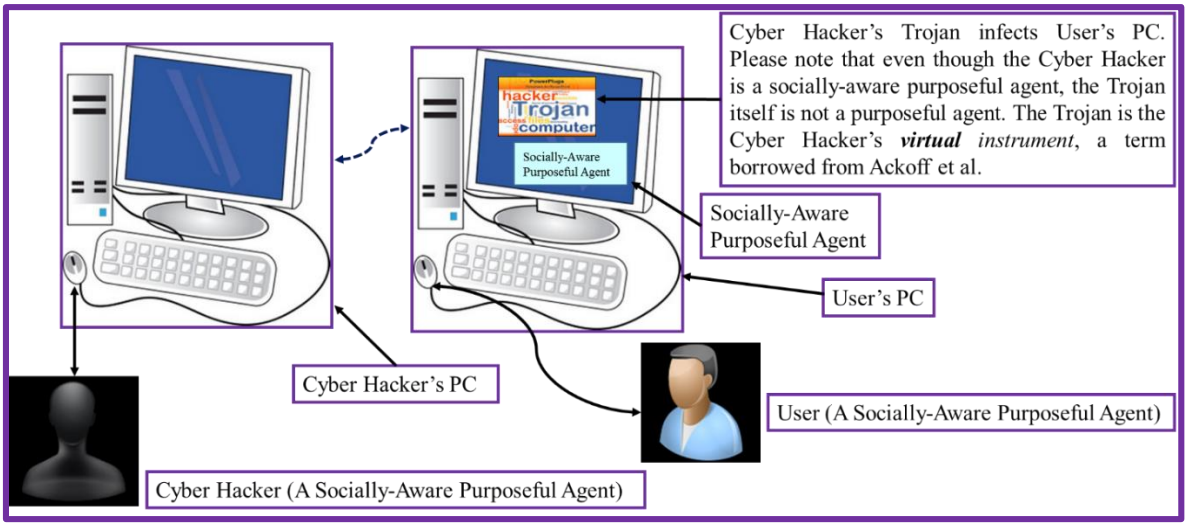

Figure 7. The Interaction between a Cyber Hacker and a Socially-Aware Purposeful Agent.

Please note that Figure 7 has our newly invented multiprocessor system (in Figure 4) which contains the ***socially-aware purposeful agent***. As we noted in Figure 4 we have also invented the ***socially-aware purposeful agent*** into the system to continuously monitor the system and to create ***a situational awareness*** (Equation 6) of any object it encounters. Figure 8 depicts the graph model, which is a dotted line to indicate that the socially-aware purposeful agent is in conflict with the cyber hacker. We then construct the polynomial, Equation 15, which represents the analytical notation of the graph, where the "+", represents the Boolean operation for addition [Lefebvre 2010]. Again, for details about the polynomial in RGT, please see the work of Lefebvre [Lefebvre 2010].

Figure 8. The Graph, Depicting Conflict between the Cyber Hacker and the Social-Aware Purposeful Agent.

$$[a] + [b] \qquad \text{Equation 15}$$

Following the same concept in Example 1 (Equation 8), we convert the polynomial into a diagonal form, Equation 16.

$$a = [a] + [b]^{[a]+[b]} \qquad \text{Equation 16}$$

Since "a" is aware of "b's" influence (the value of b is the same on the first and second tiers). Using the *reflexion function* [Lefebvre 2010] as in Example 1, we then transform the diagonal form into the final analytical form, Equation 17.

$$a = [a] + [b]^{[a]+[b]} = a + b + \overline{a + b} = 1 \qquad \text{Equation 17}$$

Now, "a" has become a superactive socially-aware purposeful agent and chooses an action to destroy the cyber hacker's instrument. Through the deceptive action that we noted before, the socially-aware purposeful agent can also take a proactive approach to getting the mental model of the cyber hacker that sent the instrument – Trojan.

Rather than using the traditional software engineering concepts such as the manifesto for agile software development to discuss agility, we have borrowed from the previous work of Alberts and Hayes [Alberts and Hayes 2003] which has much technical and scientific rigor, for our effort. A direct excerpt, from both authors' work, to describe the six key attributes of agility, will be helpful [Alberts and Hayes 2003].

Robustness: the ability to maintain effectiveness across a range of tasks, situations, and conditions;

Resilience: the ability to recover from or adjust to misfortune, damage, or a destabilizing perturbation in the environment;
Responsiveness: the ability to react to a change in the environment in a timely manner;
Flexibility: the ability to employ multiple ways to succeed and the capacity to move seamlessly between them;
Innovation: the ability to do new things and the ability to do old things in new ways; and
Adaptation: the ability to change work processes and ability to change the organization.

Our socially-aware purposeful agent can fulfill these attributes. When a socially-aware purposeful agent dynamically changes his or her behavior from elementary socially-aware purposeful agent to a non-elementary subject, he or she is indeed retaining a level of *responsiveness*. Furthermore, when a socially-aware purposeful agent employs a different set of actions to defeat a malware threat, he or she is maintaining a level of *flexibility*.

This paper has many applications. For example, we can employ the socially-aware purposeful agents to design resilient systems against cyber security threats for any organization. Most importantly, we can use socially-aware purposeful agents to create a robust system-of-systems to mitigate cyber security threats in a DoD net-centric ecosystem. In fact, Example 3 (Figures 6 and 7) demonstrates such an application of the paper. We should emphasize that Example 3 fulfills one of the tenets of President Obama's Executive Order (EO) 13636.

CONCLUSIONS

Using the *socially-aware purposeful agent* and the Reflexive Game Theory (RGT), this paper has established the framework for constructing a theoretical model for cybersecurity. Most work to date on cyber security has focused on virus scanning, with virtually no emphasis on the cyber hacker that deployed the malware on the user's endpoint devices. In fact, the concept of a malicious code which the cyber hacker employs as an instrument in a user's endpoint device was even previously unheard of in the literature on cybersecurity. Thus, for the first time, this paper has filled this missing gap by first introducing the concept of a virtual instrument to describe the malicious code. The paper has established the scientific model for the situational awareness. By extending the RGT, the paper has provided new features for an elementary subject or an elementary socially-aware purposeful agent. Of particular importance is the ability of the socially-aware purposeful agent to dynamically transition his or her behavior from an elementary subject to a non-elementary subject. Using the RGT, we have constructed the socially-aware purposeful agent with a cognitive capability. We have invented a new multiprocessor system to contain a *socially-aware purposeful agent*, which could continuously monitor the system and create *a situational awareness* of any threat object it encounters. Four examples have been given to demonstrate the application of the model. Agility of the socially-aware purposeful agent has been discussed within the context of net-centric system-of-systems' architecture.

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DR. KOFI NYAMEKYE is the president and chief executive officer of Integrated Activity-Based Simulation Research, Inc. Dr. Nyamekye has extensive prior experience as a senior research scientist in modeling and simulation of complex adaptive distributed enterprise systems for Boeing's Army Future Combat Systems (FCS). In collaboration with Dr. Vladimir Lefebvre who pioneered the Reflexive Game Theory, Dr. Nyamekye is currently using Reflexive Game Theory to model Cybersecurity risks and more importantly construct a socially-aware purposeful agent-based system (SAPABS) to mitigate Cybersecurity risks, in a Net-Centric Ecosystem (NCE). Using Experimental Laboratory for Investigating Collaboration, Information Sharing, and Trust (ELICIT) platform, he will then conduct experimental tests for information sharing and collaboration among the entities, for mitigating Cybersecurity risks, in NCE, as espoused in the **National Institute of Standards and Technology Roadmap for Improving Critical Infrastructure Cybersecurity, Section 4.8, Supply Chain Risk Management** [http://www.nist.gov/cyberframework/upload/roadmap-021214.pdf]. Dr. Nyamekye has extensively published many refereed journals on the scientific design, multi-socially-aware purposeful agent-based modeling, and simulation of integrated and adaptive C4ISR SoS. He holds a Doctor of Philosophy degree in industrial and management systems engineering from Pennsylvania State University, a Master of Science degree in mechanical engineering from Pennsylvania State University, and a Bachelor of Science degree in mechanical engineering from the University of Wisconsin-Madison. E-mail: kofinsoyameye@iabsri.net.

APPENDIX A: NIST'S CYBERSECURITY FRAMEWORK, VERSION 1.0

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Framework for Improving Critical Infrastructure Cybersecurity

Version 1.0

National Institute of Standards and Technology

February 12, 2014

Table of Contents

List of Figures

List of Tables

Executive Summary

The national and economic security of the United States depends on the reliable functioning of critical infrastructure. Cybersecurity threats exploit the increased complexity and connectivity of critical infrastructure systems, placing the Nation's security, economy, and public safety and health at risk. Similar to financial and reputational risk, cybersecurity risk affects a company's bottom line. It can drive up costs and impact revenue. It can harm an organization's ability to innovate and to gain and maintain customers.

To better address these risks, the President issued Executive Order 13636, "Improving Critical Infrastructure Cybersecurity," on February 12, 2013, which established that "[i]t is the Policy of the United States to enhance the security and resilience of the Nation's critical infrastructure and to maintain a cyber environment that encourages efficiency, innovation, and economic prosperity while promoting safety, security, business confidentiality, privacy, and civil liberties." In enacting this policy, the Executive Order calls for the development of a voluntary risk-based Cybersecurity Framework – a set of industry standards and best practices to help organizations manage cybersecurity risks. The resulting Framework, created through collaboration between government and the private sector, uses a common language to address and manage cybersecurity risk in a cost-effective way based on business needs without placing additional regulatory requirements on businesses.

The Framework focuses on using business drivers to guide cybersecurity activities and considering cybersecurity risks as part of the organization's risk management processes. The Framework consists of three parts: the Framework Core, the Framework Profile, and the Framework Implementation Tiers. The Framework Core is a set of cybersecurity activities, outcomes, and informative references that are common across critical infrastructure sectors, providing the detailed guidance for developing individual organizational Profiles. Through use of the Profiles, the Framework will help the organization align its cybersecurity activities with its business requirements, risk tolerances, and resources. The Tiers provide a mechanism for organizations to view and understand the characteristics of their approach to managing cybersecurity risk.

The Executive Order also requires that the Framework include a methodology to protect individual privacy and civil liberties when critical infrastructure organizations conduct cybersecurity activities. While processes and existing needs will differ, the Framework can assist organizations in incorporating privacy and civil liberties as part of a comprehensive cybersecurity program.

The Framework enables organizations – regardless of size, degree of cybersecurity risk, or cybersecurity sophistication – to apply the principles and best practices of risk management to improving the security and resilience of critical infrastructure. The Framework provides organization and structure to today's multiple approaches to cybersecurity by assembling standards, guidelines, and practices that are working effectively in industry today. Moreover, because it references globally recognized standards for cybersecurity, the Framework can also be

used by organizations located outside the United States and can serve as a model for international cooperation on strengthening critical infrastructure cybersecurity.

The Framework is not a one-size-fits-all approach to managing cybersecurity risk for critical infrastructure. Organizations will continue to have unique risks – different threats, different vulnerabilities, different risk tolerances – and how they implement the practices in the Framework will vary. Organizations can determine activities that are important to critical service delivery and can prioritize investments to maximize the impact of each dollar spent. Ultimately, the Framework is aimed at reducing and better managing cybersecurity risks.

The Framework is a living document and will continue to be updated and improved as industry provides feedback on implementation. As the Framework is put into practice, lessons learned will be integrated into future versions. This will ensure it is meeting the needs of critical infrastructure owners and operators in a dynamic and challenging environment of new threats, risks, and solutions.

Use of this voluntary Framework is the next step to improve the cybersecurity of our Nation's critical infrastructure – providing guidance for individual organizations, while increasing the cybersecurity posture of the Nation's critical infrastructure as a whole.

1.0 Framework Introduction

The national and economic security of the United States depends on the reliable functioning of critical infrastructure. To strengthen the resilience of this infrastructure, President Obama issued Executive Order 13636 (EO), "Improving Critical Infrastructure Cybersecurity," on February 12, 2013.[1] This Executive Order calls for the development of a voluntary Cybersecurity Framework ("Framework") that provides a "prioritized, flexible, repeatable, performance-based, and cost-effective approach" to manage cybersecurity risk for those processes, information, and systems directly involved in the delivery of critical infrastructure services. The Framework, developed in collaboration with industry, provides guidance to an organization on managing cybersecurity risk.

Critical infrastructure is defined in the EO as "systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters." Due to the increasing pressures from external and internal threats, organizations responsible for critical infrastructure need to have a consistent and iterative approach to identifying, assessing, and managing cybersecurity risk. This approach is necessary regardless of an organization's size, threat exposure, or cybersecurity sophistication today.

The critical infrastructure community includes public and private owners and operators, and other entities with a role in securing the Nation's infrastructure. Members of each critical infrastructure sector perform functions that are supported by information technology (IT) and industrial control systems (ICS).[2] This reliance on technology, communication, and the interconnectivity of IT and ICS has changed and expanded the potential vulnerabilities and increased potential risk to operations. For example, as ICS and the data produced in ICS operations are increasingly used to deliver critical services and support business decisions, the potential impacts of a cybersecurity incident on an organization's business, assets, health and safety of individuals, and the environment should be considered. To manage cybersecurity risks, a clear understanding of the organization's business drivers and security considerations specific to its use of IT and ICS is required. Because each organization's risk is unique, along with its use of IT and ICS, the tools and methods used to achieve the outcomes described by the Framework will vary.

Recognizing the role that the protection of privacy and civil liberties plays in creating greater public trust, the Executive Order requires that the Framework include a methodology to protect individual privacy and civil liberties when critical infrastructure organizations conduct cybersecurity activities. Many organizations already have processes for addressing privacy and civil liberties. The methodology is designed to complement such processes and provide guidance to facilitate privacy risk management consistent with an organization's approach to cybersecurity risk management. Integrating privacy and cybersecurity can benefit organizations by increasing customer confidence, enabling more standardized sharing of information, and simplifying operations across legal regimes.

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[1] Executive Order no. 13636, *Improving Critical Infrastructure Cybersecurity*, DCPD-201300091, February 12, 2013. http://www.gpo.gov/fdsys/pkg/FR-2013-02-19/pdf/2013-03915.pdf

[2] The DHS Critical Infrastructure program provides a listing of the sectors and their associated critical functions and value chains. http://www.dhs.gov/critical-infrastructure-sectors

To ensure extensibility and enable technical innovation, the Framework is technology neutral. The Framework relies on a variety of existing standards, guidelines, and practices to enable critical infrastructure providers to achieve resilience. By relying on those global standards, guidelines, and practices developed, managed, and updated by industry, the tools and methods available to achieve the Framework outcomes will scale across borders, acknowledge the global nature of cybersecurity risks, and evolve with technological advances and business requirements. The use of existing and emerging standards will enable economies of scale and drive the development of effective products, services, and practices that meet identified market needs. Market competition also promotes faster diffusion of these technologies and practices and realization of many benefits by the stakeholders in these sectors.

Building from those standards, guidelines, and practices, the Framework provides a common taxonomy and mechanism for organizations to:

1) Describe their current cybersecurity posture;
2) Describe their target state for cybersecurity;
3) Identify and prioritize opportunities for improvement within the context of a continuous and repeatable process;
4) Assess progress toward the target state;
5) Communicate among internal and external stakeholders about cybersecurity risk.

The Framework complements, and does not replace, an organization's risk management process and cybersecurity program. The organization can use its current processes and leverage the Framework to identify opportunities to strengthen and communicate its management of cybersecurity risk while aligning with industry practices. Alternatively, an organization without an existing cybersecurity program can use the Framework as a reference to establish one.

Just as the Framework is not industry-specific, the common taxonomy of standards, guidelines, and practices that it provides also is not country-specific. Organizations outside the United States may also use the Framework to strengthen their own cybersecurity efforts, and the Framework can contribute to developing a common language for international cooperation on critical infrastructure cybersecurity.

1.1 Overview of the Framework

The Framework is a risk-based approach to managing cybersecurity risk, and is composed of three parts: the Framework Core, the Framework Implementation Tiers, and the Framework Profiles. Each Framework component reinforces the connection between business drivers and cybersecurity activities. These components are explained below.

- The *Framework Core* is a set of cybersecurity activities, desired outcomes, and applicable references that are common across critical infrastructure sectors. The Core presents industry standards, guidelines, and practices in a manner that allows for communication of cybersecurity activities and outcomes across the organization from the executive level to the implementation/operations level. The Framework Core consists of five concurrent and continuous Functions—Identify, Protect, Detect, Respond, Recover. When considered together, these Functions provide a high-level, strategic view of the lifecycle of an organization's management of cybersecurity risk. The Framework Core

then identifies underlying key Categories and Subcategories for each Function, and matches them with example Informative References such as existing standards, guidelines, and practices for each Subcategory.

- *Framework Implementation Tiers* ("Tiers") provide context on how an organization views cybersecurity risk and the processes in place to manage that risk. Tiers describe the degree to which an organization's cybersecurity risk management practices exhibit the characteristics defined in the Framework (e.g., risk and threat aware, repeatable, and adaptive). The Tiers characterize an organization's practices over a range, from Partial (Tier 1) to Adaptive (Tier 4). These Tiers reflect a progression from informal, reactive responses to approaches that are agile and risk-informed. During the Tier selection process, an organization should consider its current risk management practices, threat environment, legal and regulatory requirements, business/mission objectives, and organizational constraints.
- A *Framework Profile* ("Profile") represents the outcomes based on business needs that an organization has selected from the Framework Categories and Subcategories. The Profile can be characterized as the alignment of standards, guidelines, and practices to the Framework Core in a particular implementation scenario. Profiles can be used to identify opportunities for improving cybersecurity posture by comparing a "Current" Profile (the "as is" state) with a "Target" Profile (the "to be" state). To develop a Profile, an organization can review all of the Categories and Subcategories and, based on business drivers and a risk assessment, determine which are most important; they can add Categories and Subcategories as needed to address the organization's risks. The Current Profile can then be used to support prioritization and measurement of progress toward the Target Profile, while factoring in other business needs including cost-effectiveness and innovation. Profiles can be used to conduct self-assessments and communicate within an organization or between organizations.

1.2 Risk Management and the Cybersecurity Framework

Risk management is the ongoing process of identifying, assessing, and responding to risk. To manage risk, organizations should understand the likelihood that an event will occur and the resulting impact. With this information, organizations can determine the acceptable level of risk for delivery of services and can express this as their risk tolerance.

With an understanding of risk tolerance, organizations can prioritize cybersecurity activities, enabling organizations to make informed decisions about cybersecurity expenditures. Implementation of risk management programs offers organizations the ability to quantify and communicate adjustments to their cybersecurity programs. Organizations may choose to handle risk in different ways, including mitigating the risk, transferring the risk, avoiding the risk, or accepting the risk, depending on the potential impact to the delivery of critical services.

The Framework uses risk management processes to enable organizations to inform and prioritize decisions regarding cybersecurity. It supports recurring risk assessments and validation of business drivers to help organizations select target states for cybersecurity activities that reflect desired outcomes. Thus, the Framework gives organizations the ability to dynamically select and direct improvement in cybersecurity risk management for the IT and ICS environments.

The Framework is adaptive to provide a flexible and risk-based implementation that can be used with a broad array of cybersecurity risk management processes. Examples of cybersecurity risk management processes include International Organization for Standardization (ISO) 31000:2009[3], ISO/IEC 27005:2011[4], National Institute of Standards and Technology (NIST) Special Publication (SP) 800-39[5], and the *Electricity Subsector Cybersecurity Risk Management Process* (RMP) guideline[6].

1.3 Document Overview

The remainder of this document contains the following sections and appendices:

- Section 2 describes the Framework components: the Framework Core, the Tiers, and the Profiles.
- Section 3 presents examples of how the Framework can be used.
- Appendix A presents the Framework Core in a tabular format: the Functions, Categories, Subcategories, and Informative References.
- Appendix B contains a glossary of selected terms.
- Appendix C lists acronyms used in this document.

[3] International Organization for Standardization, *Risk management – Principles and guidelines*, ISO 31000:2009, 2009. http://www.iso.org/iso/home/standards/iso31000.htm

[4] International Organization for Standardization/International Electrotechnical Commission, *Information technology – Security techniques – Information security risk management*, ISO/IEC 27005:2011, 2011. http://www.iso.org/iso/catalogue_detail?csnumber=56742

[5] Joint Task Force Transformation Initiative, *Managing Information Security Risk: Organization, Mission, and Information System View*, NIST Special Publication 800-39, March 2011. http://csrc.nist.gov/publications/nistpubs/800-39/SP800-39-final.pdf

[6] U.S. Department of Energy, *Electricity Subsector Cybersecurity Risk Management Process*, DOE/OE-0003, May 2012. http://energy.gov/sites/prod/files/Cybersecurity%20Risk%20Management%20Process%20Guideline%20-%20Final%20-%20May%202012.pdf

2.0 Framework Basics

The Framework provides a common language for understanding, managing, and expressing cybersecurity risk both internally and externally. It can be used to help identify and prioritize actions for reducing cybersecurity risk, and it is a tool for aligning policy, business, and technological approaches to managing that risk. It can be used to manage cybersecurity risk across entire organizations or it can be focused on the delivery of critical services within an organization. Different types of entities – including sector coordinating structures, associations, and organizations – can use the Framework for different purposes, including the creation of common Profiles.

2.1 Framework Core

The *Framework Core* provides a set of activities to achieve specific cybersecurity outcomes, and references examples of guidance to achieve those outcomes. The Core is not a checklist of actions to perform. It presents key cybersecurity outcomes identified by industry as helpful in managing cybersecurity risk. The Core comprises four elements: Functions, Categories, Subcategories, and Informative References, depicted in **Figure 1**:

Figure 1: Framework Core Structure

The Framework Core elements work together as follows:

- **Functions** organize basic cybersecurity activities at their highest level. These Functions are Identify, Protect, Detect, Respond, and Recover. They aid an organization in expressing its management of cybersecurity risk by organizing information, enabling risk management decisions, addressing threats, and improving by learning from previous activities. The Functions also align with existing methodologies for incident management and help show the impact of investments in cybersecurity. For example, investments in planning and exercises support timely response and recovery actions, resulting in reduced impact to the delivery of services.
- **Categories** are the subdivisions of a Function into groups of cybersecurity outcomes closely tied to programmatic needs and particular activities. Examples of Categories include “Asset Management,” “Access Control,” and “Detection Processes.”

- **Subcategories** further divide a Category into specific outcomes of technical and/or management activities. They provide a set of results that, while not exhaustive, help support achievement of the outcomes in each Category. Examples of Subcategories include "External information systems are catalogued," "Data-at-rest is protected," and "Notifications from detection systems are investigated."
- **Informative References** are specific sections of standards, guidelines, and practices common among critical infrastructure sectors that illustrate a method to achieve the outcomes associated with each Subcategory. The Informative References presented in the Framework Core are illustrative and not exhaustive. They are based upon cross-sector guidance most frequently referenced during the Framework development process.[7]

The five Framework Core Functions are defined below. These Functions are not intended to form a serial path, or lead to a static desired end state. Rather, the Functions can be performed concurrently and continuously to form an operational culture that addresses the dynamic cybersecurity risk. See Appendix A for the complete Framework Core listing.

- **Identify** – Develop the organizational understanding to manage cybersecurity risk to systems, assets, data, and capabilities.

  The activities in the Identify Function are foundational for effective use of the Framework. Understanding the business context, the resources that support critical functions, and the related cybersecurity risks enables an organization to focus and prioritize its efforts, consistent with its risk management strategy and business needs. Examples of outcome Categories within this Function include: Asset Management; Business Environment; Governance; Risk Assessment; and Risk Management Strategy.

- **Protect** – Develop and implement the appropriate safeguards to ensure delivery of critical infrastructure services.

  The Protect Function supports the ability to limit or contain the impact of a potential cybersecurity event. Examples of outcome Categories within this Function include: Access Control; Awareness and Training; Data Security; Information Protection Processes and Procedures; Maintenance; and Protective Technology.

- **Detect** – Develop and implement the appropriate activities to identify the occurrence of a cybersecurity event.

  The Detect Function enables timely discovery of cybersecurity events. Examples of outcome Categories within this Function include: Anomalies and Events; Security Continuous Monitoring; and Detection Processes.

- **Respond** – Develop and implement the appropriate activities to take action regarding a detected cybersecurity event.

[7] NIST developed a Compendium of informative references gathered from the Request for Information (RFI) input, Cybersecurity Framework workshops, and stakeholder engagement during the Framework development process. The Compendium includes standards, guidelines, and practices to assist with implementation. The Compendium is not intended to be an exhaustive list, but rather a starting point based on initial stakeholder input. The Compendium and other supporting material can be found at http://www.nist.gov/cyberframework/.

The Respond Function supports the ability to contain the impact of a potential cybersecurity event. Examples of outcome Categories within this Function include: Response Planning; Communications; Analysis; Mitigation; and Improvements.

- **Recover** – Develop and implement the appropriate activities to maintain plans for resilience and to restore any capabilities or services that were impaired due to a cybersecurity event.

  The Recover Function supports timely recovery to normal operations to reduce the impact from a cybersecurity event. Examples of outcome Categories within this Function include: Recovery Planning; Improvements; and Communications.

2.2 Framework Implementation Tiers

The Framework Implementation Tiers ("Tiers") provide context on how an organization views cybersecurity risk and the processes in place to manage that risk. The Tiers range from Partial (Tier 1) to Adaptive (Tier 4) and describe an increasing degree of rigor and sophistication in cybersecurity risk management practices and the extent to which cybersecurity risk management is informed by business needs and is integrated into an organization's overall risk management practices. Risk management considerations include many aspects of cybersecurity, including the degree to which privacy and civil liberties considerations are integrated into an organization's management of cybersecurity risk and potential risk responses.

The Tier selection process considers an organization's current risk management practices, threat environment, legal and regulatory requirements, business/mission objectives, and organizational constraints. Organizations should determine the desired Tier, ensuring that the selected level meets the organizational goals, is feasible to implement, and reduces cybersecurity risk to critical assets and resources to levels acceptable to the organization. Organizations should consider leveraging external guidance obtained from Federal government departments and agencies, Information Sharing and Analysis Centers (ISACs), existing maturity models, or other sources to assist in determining their desired tier.

While organizations identified as Tier 1 (Partial) are encouraged to consider moving toward Tier 2 or greater, Tiers do not represent maturity levels. Progression to higher Tiers is encouraged when such a change would reduce cybersecurity risk and be cost effective. Successful implementation of the Framework is based upon achievement of the outcomes described in the organization's Target Profile(s) and not upon Tier determination.

The Tier definitions are as follows:

Tier 1: Partial

- *Risk Management Process* – Organizational cybersecurity risk management practices are not formalized, and risk is managed in an *ad hoc* and sometimes reactive manner. Prioritization of cybersecurity activities may not be directly informed by organizational risk objectives, the threat environment, or business/mission requirements.
- *Integrated Risk Management Program* – There is limited awareness of cybersecurity risk at the organizational level and an organization-wide approach to managing cybersecurity risk has not been established. The organization implements cybersecurity risk management on an irregular, case-by-case basis due to varied experience or information gained from outside sources. The organization may not have processes that enable cybersecurity information to be shared within the organization.
- *External Participation* – An organization may not have the processes in place to participate in coordination or collaboration with other entities.

Tier 2: Risk Informed

- *Risk Management Process* – Risk management practices are approved by management but may not be established as organizational-wide policy. Prioritization of cybersecurity activities is directly informed by organizational risk objectives, the threat environment, or business/mission requirements.
- *Integrated Risk Management Program* – There is an awareness of cybersecurity risk at the organizational level but an organization-wide approach to managing cybersecurity risk has not been established. Risk-informed, management-approved processes and procedures are defined and implemented, and staff has adequate resources to perform their cybersecurity duties. Cybersecurity information is shared within the organization on an informal basis.
- *External Participation* – The organization knows its role in the larger ecosystem, but has not formalized its capabilities to interact and share information externally.

Tier 3: Repeatable

- *Risk Management Process* – The organization's risk management practices are formally approved and expressed as policy. Organizational cybersecurity practices are regularly updated based on the application of risk management processes to changes in business/mission requirements and a changing threat and technology landscape.
- *Integrated Risk Management Program* – There is an organization-wide approach to manage cybersecurity risk. Risk-informed policies, processes, and procedures are defined, implemented as intended, and reviewed. Consistent methods are in place to respond effectively to changes in risk. Personnel possess the knowledge and skills to perform their appointed roles and responsibilities.
- *External Participation* – The organization understands its dependencies and partners and receives information from these partners that enables collaboration and risk-based management decisions within the organization in response to events.

Tier 4: Adaptive

- *Risk Management Process* – The organization adapts its cybersecurity practices based on lessons learned and predictive indicators derived from previous and current cybersecurity activities. Through a process of continuous improvement incorporating advanced cybersecurity technologies and practices, the organization actively adapts to a changing cybersecurity landscape and responds to evolving and sophisticated threats in a timely manner.
- *Integrated Risk Management Program* – There is an organization-wide approach to managing cybersecurity risk that uses risk-informed policies, processes, and procedures to address potential cybersecurity events. Cybersecurity risk management is part of the organizational culture and evolves from an awareness of previous activities, information shared by other sources, and continuous awareness of activities on their systems and networks.
- *External Participation* – The organization manages risk and actively shares information with partners to ensure that accurate, current information is being distributed and consumed to improve cybersecurity before a cybersecurity event occurs.

2.3 Framework Profile

The Framework Profile ("Profile") is the alignment of the Functions, Categories, and Subcategories with the business requirements, risk tolerance, and resources of the organization. A Profile enables organizations to establish a roadmap for reducing cybersecurity risk that is well aligned with organizational and sector goals, considers legal/regulatory requirements and industry best practices, and reflects risk management priorities. Given the complexity of many organizations, they may choose to have multiple profiles, aligned with particular components and recognizing their individual needs.

Framework Profiles can be used to describe the current state or the desired target state of specific cybersecurity activities. The Current Profile indicates the cybersecurity outcomes that are currently being achieved. The Target Profile indicates the outcomes needed to achieve the desired cybersecurity risk management goals. Profiles support business/mission requirements and aid in the communication of risk within and between organizations. This Framework document does not prescribe Profile templates, allowing for flexibility in implementation.

Comparison of Profiles (e.g., the Current Profile and Target Profile) may reveal gaps to be addressed to meet cybersecurity risk management objectives. An action plan to address these gaps can contribute to the roadmap described above. Prioritization of gap mitigation is driven by the organization's business needs and risk management processes. This risk-based approach enables an organization to gauge resource estimates (e.g., staffing, funding) to achieve cybersecurity goals in a cost-effective, prioritized manner.

2.4 Coordination of Framework Implementation

Figure 2 describes a common flow of information and decisions at the following levels within an organization:

- Executive
- Business/Process
- Implementation/Operations

The executive level communicates the mission priorities, available resources, and overall risk tolerance to the business/process level. The business/process level uses the information as inputs into the risk management process, and then collaborates with the implementation/operations level to communicate business needs and create a Profile. The implementation/operations level communicates the Profile implementation progress to the business/process level. The business/process level uses this information to perform an impact assessment. Business/process level management reports the outcomes of that impact assessment to the executive level to inform the organization's overall risk management process and to the implementation/operations level for awareness of business impact.

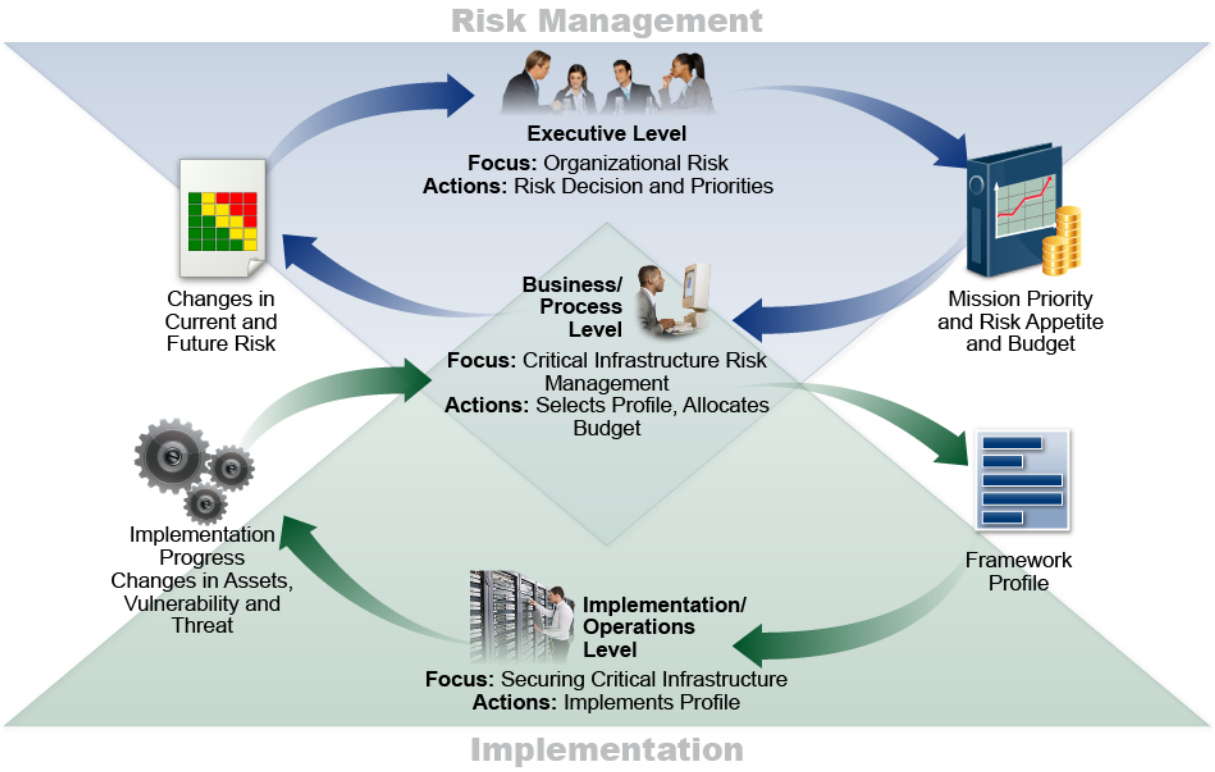


Figure 2: Notional Information and Decision Flows within an Organization

3.0 How to Use the Framework

An organization can use the Framework as a key part of its systematic process for identifying, assessing, and managing cybersecurity risk. The Framework is not designed to replace existing processes; an organization can use its current process and overlay it onto the Framework to determine gaps in its current cybersecurity risk approach and develop a roadmap to improvement. Utilizing the Framework as a cybersecurity risk management tool, an organization can determine activities that are most important to critical service delivery and prioritize expenditures to maximize the impact of the investment.

The Framework is designed to complement existing business and cybersecurity operations. It can serve as the foundation for a new cybersecurity program or a mechanism for improving an existing program. The Framework provides a means of expressing cybersecurity requirements to business partners and customers and can help identify gaps in an organization's cybersecurity practices. It also provides a general set of considerations and processes for considering privacy and civil liberties implications in the context of a cybersecurity program.

The following sections present different ways in which organizations can use the Framework.

3.1 Basic Review of Cybersecurity Practices

The Framework can be used to compare an organization's current cybersecurity activities with those outlined in the Framework Core. Through the creation of a Current Profile, organizations can examine the extent to which they are achieving the outcomes described in the Core Categories and Subcategories, aligned with the five high-level Functions: Identify, Protect, Detect, Respond, and Recover. An organization may find that it is already achieving the desired outcomes, thus managing cybersecurity commensurate with the known risk. Conversely, an organization may determine that it has opportunities to (or needs to) improve. The organization can use that information to develop an action plan to strengthen existing cybersecurity practices and reduce cybersecurity risk. An organization may also find that it is overinvesting to achieve certain outcomes. The organization can use this information to reprioritize resources to strengthen other cybersecurity practices.

While they do not replace a risk management process, these five high-level Functions will provide a concise way for senior executives and others to distill the fundamental concepts of cybersecurity risk so that they can assess how identified risks are managed, and how their organization stacks up at a high level against existing cybersecurity standards, guidelines, and practices. The Framework can also help an organization answer fundamental questions, including "How are we doing?" Then they can move in a more informed way to strengthen their cybersecurity practices where and when deemed necessary.

3.2 Establishing or Improving a Cybersecurity Program

The following steps illustrate how an organization could use the Framework to create a new cybersecurity program or improve an existing program. These steps should be repeated as necessary to continuously improve cybersecurity.

Step 1: Prioritize and Scope. The organization identifies its business/mission objectives and high-level organizational priorities. With this information, the organization makes strategic decisions regarding cybersecurity implementations and determines the scope of systems and assets that support the selected business line or process. The Framework can be adapted to support the different business lines or processes within an organization, which may have different business needs and associated risk tolerance.

Step 2: Orient. Once the scope of the cybersecurity program has been determined for the business line or process, the organization identifies related systems and assets, regulatory requirements, and overall risk approach. The organization then identifies threats to, and vulnerabilities of, those systems and assets.

Step 3: Create a Current Profile. The organization develops a Current Profile by indicating which Category and Subcategory outcomes from the Framework Core are currently being achieved.

Step 4: Conduct a Risk Assessment. This assessment could be guided by the organization's overall risk management process or previous risk assessment activities. The organization analyzes the operational environment in order to discern the likelihood of a cybersecurity event and the impact that the event could have on the organization. It is important that organizations seek to incorporate emerging risks and threat and vulnerability data to facilitate a robust understanding of the likelihood and impact of cybersecurity events.

Step 5: Create a Target Profile. The organization creates a Target Profile that focuses on the assessment of the Framework Categories and Subcategories describing the organization's desired cybersecurity outcomes. Organizations also may develop their own additional Categories and Subcategories to account for unique organizational risks. The organization may also consider influences and requirements of external stakeholders such as sector entities, customers, and business partners when creating a Target Profile.

Step 6: Determine, Analyze, and Prioritize Gaps. The organization compares the Current Profile and the Target Profile to determine gaps. Next it creates a prioritized action plan to address those gaps that draws upon mission drivers, a cost/benefit analysis, and understanding of risk to achieve the outcomes in the Target Profile. The organization then determines resources necessary to address the gaps. Using Profiles in this manner enables the organization to make informed decisions about cybersecurity activities, supports risk management, and enables the organization to perform cost-effective, targeted improvements.

Step 7: Implement Action Plan. The organization determines which actions to take in regards to the gaps, if any, identified in the previous step. It then monitors its current cybersecurity practices against the Target Profile. For further guidance, the Framework identifies example Informative References regarding the Categories and Subcategories, but organizations should determine which standards, guidelines, and practices, including those that are sector specific, work best for their needs.

An organization may repeat the steps as needed to continuously assess and improve its cybersecurity. For instance, organizations may find that more frequent repetition of the orient

step improves the quality of risk assessments. Furthermore, organizations may monitor progress through iterative updates to the Current Profile, subsequently comparing the Current Profile to the Target Profile. Organizations may also utilize this process to align their cybersecurity program with their desired Framework Implementation Tier.

3.3 Communicating Cybersecurity Requirements with Stakeholders

The Framework provides a common language to communicate requirements among interdependent stakeholders responsible for the delivery of essential critical infrastructure services. Examples include:

- An organization may utilize a Target Profile to express cybersecurity risk management requirements to an external service provider (e.g., a cloud provider to which it is exporting data).
- An organization may express its cybersecurity state through a Current Profile to report results or to compare with acquisition requirements.
- A critical infrastructure owner/operator, having identified an external partner on whom that infrastructure depends, may use a Target Profile to convey required Categories and Subcategories.
- A critical infrastructure sector may establish a Target Profile that can be used among its constituents as an initial baseline Profile to build their tailored Target Profiles.

3.4 Identifying Opportunities for New or Revised Informative References

The Framework can be used to identify opportunities for new or revised standards, guidelines, or practices where additional Informative References would help organizations address emerging needs. An organization implementing a given Subcategory, or developing a new Subcategory, might discover that there are few Informative References, if any, for a related activity. To address that need, the organization might collaborate with technology leaders and/or standards bodies to draft, develop, and coordinate standards, guidelines, or practices.

3.5 Methodology to Protect Privacy and Civil Liberties

This section describes a methodology as required by the Executive Order to address individual privacy and civil liberties implications that may result from cybersecurity operations. This methodology is intended to be a general set of considerations and processes since privacy and civil liberties implications may differ by sector or over time and organizations may address these considerations and processes with a range of technical implementations. Nonetheless, not all activities in a cybersecurity program may give rise to these considerations. Consistent with Section 3.4, technical privacy standards, guidelines, and additional best practices may need to be developed to support improved technical implementations.

Privacy and civil liberties implications may arise when personal information is used, collected, processed, maintained, or disclosed in connection with an organization's cybersecurity activities. Some examples of activities that bear privacy or civil liberties considerations may include: cybersecurity activities that result in the over-collection or over-retention of personal information; disclosure or use of personal information unrelated to cybersecurity activities; cybersecurity mitigation activities that result in denial of service or other similar potentially

adverse impacts, including activities such as some types of incident detection or monitoring that may impact freedom of expression or association.

The government and agents of the government have a direct responsibility to protect civil liberties arising from cybersecurity activities. As referenced in the methodology below, government or agents of the government that own or operate critical infrastructure should have a process in place to support compliance of cybersecurity activities with applicable privacy laws, regulations, and Constitutional requirements.

To address privacy implications, organizations may consider how, in circumstances where such measures are appropriate, their cybersecurity program might incorporate privacy principles such as: data minimization in the collection, disclosure, and retention of personal information material related to the cybersecurity incident; use limitations outside of cybersecurity activities on any information collected specifically for cybersecurity activities; transparency for certain cybersecurity activities; individual consent and redress for adverse impacts arising from use of personal information in cybersecurity activities; data quality, integrity, and security; and accountability and auditing.

As organizations assess the Framework Core in Appendix A, the following processes and activities may be considered as a means to address the above-referenced privacy and civil liberties implications:

Governance of cybersecurity risk

- An organization's assessment of cybersecurity risk and potential risk responses considers the privacy implications of its cybersecurity program
- Individuals with cybersecurity-related privacy responsibilities report to appropriate management and are appropriately trained
- Process is in place to support compliance of cybersecurity activities with applicable privacy laws, regulations, and Constitutional requirements
- Process is in place to assess implementation of the foregoing organizational measures and controls

Approaches to identifying and authorizing individuals to access organizational assets and systems

- Steps are taken to identify and address the privacy implications of access control measures to the extent that they involve collection, disclosure, or use of personal information

Awareness and training measures

- Applicable information from organizational privacy policies is included in cybersecurity workforce training and awareness activities
- Service providers that provide cybersecurity-related services for the organization are informed about the organization's applicable privacy policies

Anomalous activity detection and system and assets monitoring

- Process is in place to conduct a privacy review of an organization's anomalous activity detection and cybersecurity monitoring

Response activities, including information sharing or other mitigation efforts

- Process is in place to assess and address whether, when, how, and the extent to which personal information is shared outside the organization as part of cybersecurity information sharing activities
- Process is in place to conduct a privacy review of an organization's cybersecurity mitigation efforts

Appendix A: Framework Core

This appendix presents the Framework Core: a listing of Functions, Categories, Subcategories, and Informative References that describe specific cybersecurity activities that are common across all critical infrastructure sectors. The chosen presentation format for the Framework Core does not suggest a specific implementation order or imply a degree of importance of the Categories, Subcategories, and Informative References. The Framework Core presented in this appendix represents a common set of activities for managing cybersecurity risk. While the Framework is not exhaustive, it is extensible, allowing organizations, sectors, and other entities to use Subcategories and Informative References that are cost-effective and efficient and that enable them to manage their cybersecurity risk. Activities can be selected from the Framework Core during the Profile creation process and additional Categories, Subcategories, and Informative References may be added to the Profile. An organization's risk management processes, legal/regulatory requirements, business/mission objectives, and organizational constraints guide the selection of these activities during Profile creation. Personal information is considered a component of data or assets referenced in the Categories when assessing security risks and protections.

While the intended outcomes identified in the Functions, Categories, and Subcategories are the same for IT and ICS, the operational environments and considerations for IT and ICS differ. ICS have a direct effect on the physical world, including potential risks to the health and safety of individuals, and impact on the environment. Additionally, ICS have unique performance and reliability requirements compared with IT, and the goals of safety and efficiency must be considered when implementing cybersecurity measures.

For ease of use, each component of the Framework Core is given a unique identifier. Functions and Categories each have a unique alphabetic identifier, as shown in Table 1. Subcategories within each Category are referenced numerically; the unique identifier for each Subcategory is included in Table 2.

Additional supporting material relating to the Framework can be found on the NIST website at http://www.nist.gov/cyberframework/.

Table 1: Function and Category Unique Identifiers

Function Unique Identifier	Function	Category Unique Identifier	Category
ID	Identify	ID.AM	Asset Management
		ID.BE	Business Environment
		ID.GV	Governance
		ID.RA	Risk Assessment
		ID.RM	Risk Management Strategy
PR	Protect	PR.AC	Access Control
		PR.AT	Awareness and Training
		PR.DS	Data Security
		PR.IP	Information Protection Processes and Procedures
		PR.MA	Maintenance
		PR.PT	Protective Technology
DE	Detect	DE.AE	Anomalies and Events
		DE.CM	Security Continuous Monitoring
		DE.DP	Detection Processes
RS	Respond	RS.RP	Response Planning
		RS.CO	Communications
		RS.AN	Analysis
		RS.MI	Mitigation
		RS.IM	Improvements
RC	Recover	RC.RP	Recovery Planning
		RC.IM	Improvements
		RC.CO	Communications

Table 2: Framework Core

Function	Category	Subcategory	Informative References
IDENTIFY (ID)	**Asset Management (ID.AM):** The data, personnel, devices, systems, and facilities that enable the organization to achieve business purposes are identified and managed consistent with their relative importance to business objectives and the organization's risk strategy.	**ID.AM-1**: Physical devices and systems within the organization are inventoried	• **CCS CSC** 1 • **COBIT 5** BAI09.01, BAI09.02 • **ISA 62443-2-1:2009** 4.2.3.4 • **ISA 62443-3-3:2013** SR 7.8 • **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2 • **NIST SP 800-53 Rev. 4** CM-8
		ID.AM-2: Software platforms and applications within the organization are inventoried	• **CCS CSC** 2 • **COBIT 5** BAI09.01, BAI09.02, BAI09.05 • **ISA 62443-2-1:2009** 4.2.3.4 • **ISA 62443-3-3:2013** SR 7.8 • **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2 • **NIST SP 800-53 Rev. 4** CM-8
		ID.AM-3: Organizational communication and data flows are mapped	• **CCS CSC** 1 • **COBIT 5** DSS05.02 • **ISA 62443-2-1:2009** 4.2.3.4 • **ISO/IEC 27001:2013** A.13.2.1 • **NIST SP 800-53 Rev. 4** AC-4, CA-3, CA-9, PL-8
		ID.AM-4: External information systems are catalogued	• **COBIT 5** APO02.02 • **ISO/IEC 27001:2013** A.11.2.6 • **NIST SP 800-53 Rev. 4** AC-20, SA-9
		ID.AM-5: Resources (e.g., hardware, devices, data, and software) are prioritized based on their classification, criticality, and business value	• **COBIT 5** APO03.03, APO03.04, BAI09.02 • **ISA 62443-2-1:2009** 4.2.3.6 • **ISO/IEC 27001:2013** A.8.2.1 • **NIST SP 800-53 Rev. 4** CP-2, RA-2, SA-14
		ID.AM-6: Cybersecurity roles and responsibilities for the entire workforce and third-party stakeholders (e.g., suppliers, customers, partners) are established	• **COBIT 5** APO01.02, DSS06.03 • **ISA 62443-2-1:2009** 4.3.2.3.3 • **ISO/IEC 27001:2013** A.6.1.1

Function	Category	Subcategory	Informative References
			• **NIST SP 800-53 Rev. 4** CP-2, PS-7, PM-11
	Business Environment (ID.BE): The organization's mission, objectives, stakeholders, and activities are understood and prioritized; this information is used to inform cybersecurity roles, responsibilities, and risk management decisions.	**ID.BE-1:** The organization's role in the supply chain is identified and communicated	• **COBIT 5** APO08.04, APO08.05, APO10.03, APO10.04, APO10.05 • **ISO/IEC 27001:2013** A.15.1.3, A.15.2.1, A.15.2.2 • **NIST SP 800-53 Rev. 4** CP-2, SA-12
		ID.BE-2: The organization's place in critical infrastructure and its industry sector is identified and communicated	• **COBIT 5** APO02.06, APO03.01 • **NIST SP 800-53 Rev. 4** PM-8
		ID.BE-3: Priorities for organizational mission, objectives, and activities are established and communicated	• **COBIT 5** APO02.01, APO02.06, APO03.01 • **ISA 62443-2-1:2009** 4.2.2.1, 4.2.3.6 • **NIST SP 800-53 Rev. 4** PM-11, SA-14
		ID.BE-4: Dependencies and critical functions for delivery of critical services are established	• **ISO/IEC 27001:2013** A.11.2.2, A.11.2.3, A.12.1.3 • **NIST SP 800-53 Rev. 4** CP-8, PE-9, PE-11, PM-8, SA-14
		ID.BE-5: Resilience requirements to support delivery of critical services are established	• **COBIT 5** DSS04.02 • **ISO/IEC 27001:2013** A.11.1.4, A.17.1.1, A.17.1.2, A.17.2.1 • **NIST SP 800-53 Rev. 4** CP-2, CP-11, SA-14
	Governance (ID.GV): The policies, procedures, and processes to manage and monitor the organization's regulatory, legal, risk, environmental, and operational requirements are understood and inform the management of cybersecurity risk.	**ID.GV-1:** Organizational information security policy is established	• **COBIT 5** APO01.03, EDM01.01, EDM01.02 • **ISA 62443-2-1:2009** 4.3.2.6 • **ISO/IEC 27001:2013** A.5.1.1 • **NIST SP 800-53 Rev. 4** -1 controls from all families
		ID.GV-2: Information security roles & responsibilities are coordinated and aligned with internal roles and external partners	• **COBIT 5** APO13.12 • **ISA 62443-2-1:2009** 4.3.2.3.3 • **ISO/IEC 27001:2013** A.6.1.1, A.7.2.1 • **NIST SP 800-53 Rev. 4** PM-1, PS-7
		ID.GV-3: Legal and regulatory requirements regarding cybersecurity,	• **COBIT 5** MEA03.01, MEA03.04 • **ISA 62443-2-1:2009** 4.4.3.7

Function	Category	Subcategory	Informative References
		including privacy and civil liberties obligations, are understood and managed	• **ISO/IEC 27001:2013** A.18.1 • **NIST SP 800-53 Rev. 4** -1 controls from all families (except PM-1)
		ID.GV-4: Governance and risk management processes address cybersecurity risks	• **COBIT 5** DSS04.02 • **ISA 62443-2-1:2009** 4.2.3.1, 4.2.3.3, 4.2.3.8, 4.2.3.9, 4.2.3.11, 4.3.2.4.3, 4.3.2.6.3 • **NIST SP 800-53 Rev. 4** PM-9, PM-11
	Risk Assessment (ID.RA): The organization understands the cybersecurity risk to organizational operations (including mission, functions, image, or reputation), organizational assets, and individuals.	**ID.RA-1:** Asset vulnerabilities are identified and documented	• **CCS CSC** 4 • **COBIT 5** APO12.01, APO12.02, APO12.03, APO12.04 • **ISA 62443-2-1:2009** 4.2.3, 4.2.3.7, 4.2.3.9, 4.2.3.12 • **ISO/IEC 27001:2013** A.12.6.1, A.18.2.3 • **NIST SP 800-53 Rev. 4** CA-2, CA-7, CA-8, RA-3, RA-5, SA-5, SA-11, SI-2, SI-4, SI-5
		ID.RA-2: Threat and vulnerability information is received from information sharing forums and sources	• **ISA 62443-2-1:2009** 4.2.3, 4.2.3.9, 4.2.3.12 • **ISO/IEC 27001:2013** A.6.1.4 • **NIST SP 800-53 Rev. 4** PM-15, PM-16, SI-5
		ID.RA-3: Threats, both internal and external, are identified and documented	• **COBIT 5** APO12.01, APO12.02, APO12.03, APO12.04 • **ISA 62443-2-1:2009** 4.2.3, 4.2.3.9, 4.2.3.12 • **NIST SP 800-53 Rev. 4** RA-3, SI-5, PM-12, PM-16
		ID.RA-4: Potential business impacts and likelihoods are identified	• **COBIT 5** DSS04.02 • **ISA 62443-2-1:2009** 4.2.3, 4.2.3.9, 4.2.3.12 • **NIST SP 800-53 Rev. 4** RA-2, RA-3, PM-9, PM-11, SA-14
		ID.RA-5: Threats, vulnerabilities, likelihoods, and impacts are used to determine risk	• **COBIT 5** APO12.02 • **ISO/IEC 27001:2013** A.12.6.1 • **NIST SP 800-53 Rev. 4** RA-2, RA-3, PM-16
		ID.RA-6: Risk responses are identified and	• **COBIT 5** APO12.05, APO13.02

Function	Category	Subcategory	Informative References
		prioritized	• **NIST SP 800-53 Rev. 4** PM-4, PM-9
	Risk Management Strategy (ID.RM): The organization's priorities, constraints, risk tolerances, and assumptions are established and used to support operational risk decisions.	**ID.RM-1:** Risk management processes are established, managed, and agreed to by organizational stakeholders	• **COBIT 5** APO12.04, APO12.05, APO13.02, BAI02.03, BAI04.02 • **ISA 62443-2-1:2009** 4.3.4.2 • **NIST SP 800-53 Rev. 4** PM-9
		ID.RM-2: Organizational risk tolerance is determined and clearly expressed	• **COBIT 5** APO12.06 • **ISA 62443-2-1:2009** 4.3.2.6.5 • **NIST SP 800-53 Rev. 4** PM-9
		ID.RM-3: The organization's determination of risk tolerance is informed by its role in critical infrastructure and sector specific risk analysis	• **NIST SP 800-53 Rev. 4** PM-8, PM-9, PM-11, SA-14
PROTECT (PR)	**Access Control (PR.AC):** Access to assets and associated facilities is limited to authorized users, processes, or devices, and to authorized activities and transactions.	**PR.AC-1:** Identities and credentials are managed for authorized devices and users	• **CCS CSC** 16 • **COBIT 5** DSS05.04, DSS06.03 • **ISA 62443-2-1:2009** 4.3.3.5.1 • **ISA 62443-3-3:2013** SR 1.1, SR 1.2, SR 1.3, SR 1.4, SR 1.5, SR 1.7, SR 1.8, SR 1.9 • **ISO/IEC 27001:2013** A.9.2.1, A.9.2.2, A.9.2.4, A.9.3.1, A.9.4.2, A.9.4.3 • **NIST SP 800-53 Rev. 4** AC-2, IA Family
		PR.AC-2: Physical access to assets is managed and protected	• **COBIT 5** DSS01.04, DSS05.05 • **ISA 62443-2-1:2009** 4.3.3.3.2, 4.3.3.3.8 • **ISO/IEC 27001:2013** A.11.1.1, A.11.1.2, A.11.1.4, A.11.1.6, A.11.2.3 • **NIST SP 800-53 Rev. 4** PE-2, PE-3, PE-4, PE-5, PE-6, PE-9
		PR.AC-3: Remote access is managed	• **COBIT 5** APO13.01, DSS01.04, DSS05.03 • **ISA 62443-2-1:2009** 4.3.3.6.6 • **ISA 62443-3-3:2013** SR 1.13, SR 2.6 • **ISO/IEC 27001:2013** A.6.2.2, A.13.1.1, A.13.2.1

Function	Category	Subcategory	Informative References
			• **NIST SP 800-53 Rev. 4** AC-17, AC-19, AC-20
		PR.AC-4: Access permissions are managed, incorporating the principles of least privilege and separation of duties	• **CCS CSC** 12, 15 • **ISA 62443-2-1:2009** 4.3.3.7.3 • **ISA 62443-3-3:2013** SR 2.1 • **ISO/IEC 27001:2013** A.6.1.2, A.9.1.2, A.9.2.3, A.9.4.1, A.9.4.4 • **NIST SP 800-53 Rev. 4** AC-2, AC-3, AC-5, AC-6, AC-16
		PR.AC-5: Network integrity is protected, incorporating network segregation where appropriate	• **ISA 62443-2-1:2009** 4.3.3.4 • **ISA 62443-3-3:2013** SR 3.1, SR 3.8 • **ISO/IEC 27001:2013** A.13.1.1, A.13.1.3, A.13.2.1 • **NIST SP 800-53 Rev. 4** AC-4, SC-7
	Awareness and Training (PR.AT): The organization's personnel and partners are provided cybersecurity awareness education and are adequately trained to perform their information security-related duties and responsibilities consistent with related policies, procedures, and agreements.	**PR.AT-1:** All users are informed and trained	• **CCS CSC** 9 • **COBIT 5** APO07.03, BAI05.07 • **ISA 62443-2-1:2009** 4.3.2.4.2 • **ISO/IEC 27001:2013** A.7.2.2 • **NIST SP 800-53 Rev. 4** AT-2, PM-13
		PR.AT-2: Privileged users understand roles & responsibilities	• **CCS CSC** 9 • **COBIT 5** APO07.02, DSS06.03 • **ISA 62443-2-1:2009** 4.3.2.4.2, 4.3.2.4.3 • **ISO/IEC 27001:2013** A.6.1.1, A.7.2.2 • **NIST SP 800-53 Rev. 4** AT-3, PM-13
		PR.AT-3: Third-party stakeholders (e.g., suppliers, customers, partners) understand roles & responsibilities	• **CCS CSC** 9 • **COBIT 5** APO07.03, APO10.04, APO10.05 • **ISA 62443-2-1:2009** 4.3.2.4.2 • **ISO/IEC 27001:2013** A.6.1.1, A.7.2.2 • **NIST SP 800-53 Rev. 4** PS-7, SA-9
		PR.AT-4: Senior executives understand roles & responsibilities	• **CCS CSC** 9 • **COBIT 5** APO07.03

Function	Category	Subcategory	Informative References
			• **ISA 62443-2-1:2009** 4.3.2.4.2 • **ISO/IEC 27001:2013** A.6.1.1, A.7.2.2, • **NIST SP 800-53 Rev. 4** AT-3, PM-13
		PR.AT-5: Physical and information security personnel understand roles & responsibilities	• **CCS CSC** 9 • **COBIT 5** APO07.03 • **ISA 62443-2-1:2009** 4.3.2.4.2 • **ISO/IEC 27001:2013** A.6.1.1, A.7.2.2, • **NIST SP 800-53 Rev. 4** AT-3, PM-13
	Data Security (PR.DS): Information and records (data) are managed consistent with the organization's risk strategy to protect the confidentiality, integrity, and availability of information.	**PR.DS-1:** Data-at-rest is protected	• **CCS CSC** 17 • **COBIT 5** APO01.06, BAI02.01, BAI06.01, DSS06.06 • **ISA 62443-3-3:2013** SR 3.4, SR 4.1 • **ISO/IEC 27001:2013** A.8.2.3 • **NIST SP 800-53 Rev. 4** SC-28
		PR.DS-2: Data-in-transit is protected	• **CCS CSC** 17 • **COBIT 5** APO01.06, DSS06.06 • **ISA 62443-3-3:2013** SR 3.1, SR 3.8, SR 4.1, SR 4.2 • **ISO/IEC 27001:2013** A.8.2.3, A.13.1.1, A.13.2.1, A.13.2.3, A.14.1.2, A.14.1.3 • **NIST SP 800-53 Rev. 4** SC-8
		PR.DS-3: Assets are formally managed throughout removal, transfers, and disposition	• **COBIT 5** BAI09.03 • **ISA 62443-2-1:2009** 4. 4.3.3.3.9, 4.3.4.4.1 • **ISA 62443-3-3:2013** SR 4.2 • **ISO/IEC 27001:2013** A.8.2.3, A.8.3.1, A.8.3.2, A.8.3.3, A.11.2.7 • **NIST SP 800-53 Rev. 4** CM-8, MP-6, PE-16
		PR.DS-4: Adequate capacity to ensure availability is maintained	• **COBIT 5** APO13.01 • **ISA 62443-3-3:2013** SR 7.1, SR 7.2 • **ISO/IEC 27001:2013** A.12.3.1

Function	Category	Subcategory	Informative References
			• **NIST SP 800-53 Rev. 4** AU-4, CP-2, SC-5
		PR.DS-5: Protections against data leaks are implemented	• **CCS CSC** 17 • **COBIT 5** APO01.06 • **ISA 62443-3-3:2013** SR 5.2 • **ISO/IEC 27001:2013** A.6.1.2, A.7.1.1, A.7.1.2, A.7.3.1, A.8.2.2, A.8.2.3, A.9.1.1, A.9.1.2, A.9.2.3, A.9.4.1, A.9.4.4, A.9.4.5, A.13.1.3, A.13.2.1, A.13.2.3, A.13.2.4, A.14.1.2, A.14.1.3 • **NIST SP 800-53 Rev. 4** AC-4, AC-5, AC-6, PE-19, PS-3, PS-6, SC-7, SC-8, SC-13, SC-31, SI-4
		PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity	• **ISA 62443-3-3:2013** SR 3.1, SR 3.3, SR 3.4, SR 3.8 • **ISO/IEC 27001:2013** A.12.2.1, A.12.5.1, A.14.1.2, A.14.1.3 • **NIST SP 800-53 Rev. 4** SI-7
		PR.DS-7: The development and testing environment(s) are separate from the production environment	• **COBIT 5** BAI07.04 • **ISO/IEC 27001:2013** A.12.1.4 • **NIST SP 800-53 Rev. 4** CM-2
	Information Protection Processes and Procedures (PR.IP): Security policies (that address purpose, scope, roles, responsibilities, management commitment, and coordination among organizational entities), processes, and procedures are maintained and used to manage protection of information systems and assets.	**PR.IP-1:** A baseline configuration of information technology/industrial control systems is created and maintained	• **CCS CSC** 3, 10 • **COBIT 5** BAI10.01, BAI10.02, BAI10.03, BAI10.05 • **ISA 62443-2-1:2009** 4.3.4.3.2, 4.3.4.3.3 • **ISA 62443-3-3:2013** SR 7.6 • **ISO/IEC 27001:2013** A.12.1.2, A.12.5.1, A.12.6.2, A.14.2.2, A.14.2.3, A.14.2.4 • **NIST SP 800-53 Rev. 4** CM-2, CM-3, CM-4, CM-5, CM-6, CM-7, CM-9, SA-10
		PR.IP-2: A System Development Life Cycle to manage systems is implemented	• **COBIT 5** APO13.01 • **ISA 62443-2-1:2009** 4.3.4.3.3 • **ISO/IEC 27001:2013** A.6.1.5, A.14.1.1, A.14.2.1, A.14.2.5

Function	Category	Subcategory	Informative References
			• **NIST SP 800-53 Rev. 4** SA-3, SA-4, SA-8, SA-10, SA-11, SA-12, SA-15, SA-17, PL-8
		PR.IP-3: Configuration change control processes are in place	• **COBIT 5** BAI06.01, BAI01.06 • **ISA 62443-2-1:2009** 4.3.4.3.2, 4.3.4.3.3 • **ISA 62443-3-3:2013** SR 7.6 • **ISO/IEC 27001:2013** A.12.1.2, A.12.5.1, A.12.6.2, A.14.2.2, A.14.2.3, A.14.2.4 • **NIST SP 800-53 Rev. 4** CM-3, CM-4, SA-10
		PR.IP-4: Backups of information are conducted, maintained, and tested periodically	• **COBIT 5** APO13.01 • **ISA 62443-2-1:2009** 4.3.4.3.9 • **ISA 62443-3-3:2013** SR 7.3, SR 7.4 • **ISO/IEC 27001:2013** A.12.3.1, A.17.1.2A.17.1.3, A.18.1.3 • **NIST SP 800-53 Rev. 4** CP-4, CP-6, CP-9
		PR.IP-5: Policy and regulations regarding the physical operating environment for organizational assets are met	• **COBIT 5** DSS01.04, DSS05.05 • **ISA 62443-2-1:2009** 4.3.3.3.1 4.3.3.3.2, 4.3.3.3.3, 4.3.3.3.5, 4.3.3.3.6 • **ISO/IEC 27001:2013** A.11.1.4, A.11.2.1, A.11.2.2, A.11.2.3 • **NIST SP 800-53 Rev. 4** PE-10, PE-12, PE-13, PE-14, PE-15, PE-18
		PR.IP-6: Data is destroyed according to policy	• **COBIT 5** BAI09.03 • **ISA 62443-2-1:2009** 4.3.4.4.4 • **ISA 62443-3-3:2013** SR 4.2 • **ISO/IEC 27001:2013** A.8.2.3, A.8.3.1, A.8.3.2, A.11.2.7 • **NIST SP 800-53 Rev. 4** MP-6
		PR.IP-7: Protection processes are continuously improved	• **COBIT 5** APO11.06, DSS04.05 • **ISA 62443-2-1:2009** 4.4.3.1, 4.4.3.2, 4.4.3.3, 4.4.3.4, 4.4.3.5, 4.4.3.6, 4.4.3.7, 4.4.3.8 • **NIST SP 800-53 Rev. 4** CA-2, CA-7, CP-2, IR-

Function	Category	Subcategory	Informative References
			8, PL-2, PM-6
		PR.IP-8: Effectiveness of protection technologies is shared with appropriate parties	• **ISO/IEC 27001:2013** A.16.1.6 • **NIST SP 800-53 Rev. 4** AC-21, CA-7, SI-4
		PR.IP-9: Response plans (Incident Response and Business Continuity) and recovery plans (Incident Recovery and Disaster Recovery) are in place and managed	• **COBIT 5** DSS04.03 • **ISA 62443-2-1:2009** 4.3.2.5.3, 4.3.4.5.1 • **ISO/IEC 27001:2013** A.16.1.1, A.17.1.1, A.17.1.2 • **NIST SP 800-53 Rev. 4** CP-2, IR-8
		PR.IP-10: Response and recovery plans are tested	• **ISA 62443-2-1:2009** 4.3.2.5.7, 4.3.4.5.11 • **ISA 62443-3-3:2013** SR 3.3 • **ISO/IEC 27001:2013** A.17.1.3 • **NIST SP 800-53 Rev.4** CP-4, IR-3, PM-14
		PR.IP-11: Cybersecurity is included in human resources practices (e.g., deprovisioning, personnel screening)	• **COBIT 5** APO07.01, APO07.02, APO07.03, APO07.04, APO07.05 • **ISA 62443-2-1:2009** 4.3.3.2.1, 4.3.3.2.2, 4.3.3.2.3 • **ISO/IEC 27001:2013** A.7.1.1, A.7.3.1, A.8.1.4 • **NIST SP 800-53 Rev. 4** PS Family
		PR.IP-12: A vulnerability management plan is developed and implemented	• **ISO/IEC 27001:2013** A.12.6.1, A.18.2.2 • **NIST SP 800-53 Rev. 4** RA-3, RA-5, SI-2
	Maintenance (PR.MA): Maintenance and repairs of industrial control and information system components is performed consistent with policies and procedures.	**PR.MA-1:** Maintenance and repair of organizational assets is performed and logged in a timely manner, with approved and controlled tools	• **COBIT 5** BAI09.03 • **ISA 62443-2-1:2009** 4.3.3.3.7 • **ISO/IEC 27001:2013** A.11.1.2, A.11.2.4, A.11.2.5 • **NIST SP 800-53 Rev. 4** MA-2, MA-3, MA-5
		PR.MA-2: Remote maintenance of organizational assets is approved, logged, and performed in a manner that prevents unauthorized access	• **COBIT 5** DSS05.04 • **ISA 62443-2-1:2009** 4.3.3.6.5, 4.3.3.6.6, 4.3.3.6.7, 4.4.4.6.8 • **ISO/IEC 27001:2013** A.11.2.4, A.15.1.1, A.15.2.1

Function	Category	Subcategory	Informative References
			• **NIST SP 800-53 Rev. 4** MA-4
	Protective Technology (PR.PT): Technical security solutions are managed to ensure the security and resilience of systems and assets, consistent with related policies, procedures, and agreements.	**PR.PT-1:** Audit/log records are determined, documented, implemented, and reviewed in accordance with policy	• **CCS CSC** 14 • **COBIT 5** APO11.04 • **ISA 62443-2-1:2009** 4.3.3.3.9, 4.3.3.5.8, 4.3.4.4.7, 4.4.2.1, 4.4.2.2, 4.4.2.4 • **ISA 62443-3-3:2013** SR 2.8, SR 2.9, SR 2.10, SR 2.11, SR 2.12 • **ISO/IEC 27001:2013** A.12.4.1, A.12.4.2, A.12.4.3, A.12.4.4, A.12.7.1 • **NIST SP 800-53 Rev. 4** AU Family
		PR.PT-2: Removable media is protected and its use restricted according to policy	• **COBIT 5** DSS05.02, APO13.01 • **ISA 62443-3-3:2013** SR 2.3 • **ISO/IEC 27001:2013** A.8.2.2, A.8.2.3, A.8.3.1, A.8.3.3, A.11.2.9 • **NIST SP 800-53 Rev. 4** MP-2, MP-4, MP-5, MP-7
		PR.PT-3: Access to systems and assets is controlled, incorporating the principle of least functionality	• **COBIT 5** DSS05.02 • **ISA 62443-2-1:2009** 4.3.3.5.1, 4.3.3.5.2, 4.3.3.5.3, 4.3.3.5.4, 4.3.3.5.5, 4.3.3.5.6, 4.3.3.5.7, 4.3.3.5.8, 4.3.3.6.1, 4.3.3.6.2, 4.3.3.6.3, 4.3.3.6.4, 4.3.3.6.5, 4.3.3.6.6, 4.3.3.6.7, 4.3.3.6.8, 4.3.3.6.9, 4.3.3.7.1, 4.3.3.7.2, 4.3.3.7.3, 4.3.3.7.4 • **ISA 62443-3-3:2013** SR 1.1, SR 1.2, SR 1.3, SR 1.4, SR 1.5, SR 1.6, SR 1.7, SR 1.8, SR 1.9, SR 1.10, SR 1.11, SR 1.12, SR 1.13, SR 2.1, SR 2.2, SR 2.3, SR 2.4, SR 2.5, SR 2.6, SR 2.7 • **ISO/IEC 27001:2013** A.9.1.2 • **NIST SP 800-53 Rev. 4** AC-3, CM-7
		PR.PT-4: Communications and control networks are protected	• **CCS CSC** 7 • **COBIT 5** DSS05.02, APO13.01 • **ISA 62443-3-3:2013** SR 3.1, SR 3.5, SR 3.8, SR 4.1, SR 4.3, SR 5.1, SR 5.2, SR 5.3, SR 7.1,

Function	Category	Subcategory	Informative References
			SR 7.6 • **ISO/IEC 27001:2013** A.13.1.1, A.13.2.1 • **NIST SP 800-53 Rev. 4** AC-4, AC-17, AC-18, CP-8, SC-7
DETECT (DE)	**Anomalies and Events (DE.AE):** Anomalous activity is detected in a timely manner and the potential impact of events is understood.	**DE.AE-1:** A baseline of network operations and expected data flows for users and systems is established and managed	• **COBIT 5** DSS03.01 • **ISA 62443-2-1:2009** 4.4.3.3 • **NIST SP 800-53 Rev. 4** AC-4, CA-3, CM-2, SI-4
		DE.AE-2: Detected events are analyzed to understand attack targets and methods	• **ISA 62443-2-1:2009** 4.3.4.5.6, 4.3.4.5.7, 4.3.4.5.8 • **ISA 62443-3-3:2013** SR 2.8, SR 2.9, SR 2.10, SR 2.11, SR 2.12, SR 3.9, SR 6.1, SR 6.2 • **ISO/IEC 27001:2013** A.16.1.1, A.16.1.4 • **NIST SP 800-53 Rev. 4** AU-6, CA-7, IR-4, SI-4
		DE.AE-3: Event data are aggregated and correlated from multiple sources and sensors	• **ISA 62443-3-3:2013** SR 6.1 • **NIST SP 800-53 Rev. 4** AU-6, CA-7, IR-4, IR-5, IR-8, SI-4
		DE.AE-4: Impact of events is determined	• **COBIT 5** APO12.06 • **NIST SP 800-53 Rev. 4** CP-2, IR-4, RA-3, SI -4
		DE.AE-5: Incident alert thresholds are established	• **COBIT 5** APO12.06 • **ISA 62443-2-1:2009** 4.2.3.10 • **NIST SP 800-53 Rev. 4** IR-4, IR-5, IR-8
	Security Continuous Monitoring (DE.CM): The information system and assets are monitored at discrete intervals to identify cybersecurity events and verify the effectiveness of protective measures.	**DE.CM-1:** The network is monitored to detect potential cybersecurity events	• **CCS CSC** 14, 16 • **COBIT 5** DSS05.07 • **ISA 62443-3-3:2013** SR 6.2 • **NIST SP 800-53 Rev. 4** AC-2, AU-12, CA-7, CM-3, SC-5, SC-7, SI-4
		DE.CM-2: The physical environment is	• **ISA 62443-2-1:2009** 4.3.3.3.8

Function	Category	Subcategory	Informative References
		monitored to detect potential cybersecurity events	• **NIST SP 800-53 Rev. 4** CA-7, PE-3, PE-6, PE-20
		DE.CM-3: Personnel activity is monitored to detect potential cybersecurity events	• **ISA 62443-3-3:2013** SR 6.2 • **ISO/IEC 27001:2013** A.12.4.1 • **NIST SP 800-53 Rev. 4** AC-2, AU-12, AU-13, CA-7, CM-10, CM-11
		DE.CM-4: Malicious code is detected	• **CCS CSC** 5 • **COBIT 5** DSS05.01 • **ISA 62443-2-1:2009** 4.3.4.3.8 • **ISA 62443-3-3:2013** SR 3.2 • **ISO/IEC 27001:2013** A.12.2.1 • **NIST SP 800-53 Rev. 4** SI-3
		DE.CM-5: Unauthorized mobile code is detected	• **ISA 62443-3-3:2013** SR 2.4 • **ISO/IEC 27001:2013** A.12.5.1 • **NIST SP 800-53 Rev. 4** SC-18, SI-4. SC-44
		DE.CM-6: External service provider activity is monitored to detect potential cybersecurity events	• **COBIT 5** APO07.06 • **ISO/IEC 27001:2013** A.14.2.7, A.15.2.1 • **NIST SP 800-53 Rev. 4** CA-7, PS-7, SA-4, SA-9, SI-4
		DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed	• **NIST SP 800-53 Rev. 4** AU-12, CA-7, CM-3, CM-8, PE-3, PE-6, PE-20, SI-4
		DE.CM-8: Vulnerability scans are performed	• **COBIT 5** BAI03.10 • **ISA 62443-2-1:2009** 4.2.3.1, 4.2.3.7 • **ISO/IEC 27001:2013** A.12.6.1 • **NIST SP 800-53 Rev. 4** RA-5
	Detection Processes (DE.DP): Detection processes and procedures are maintained and tested to ensure timely and	**DE.DP-1:** Roles and responsibilities for detection are well defined to ensure accountability	• **CCS CSC** 5 • **COBIT 5** DSS05.01 • **ISA 62443-2-1:2009** 4.4.3.1 • **ISO/IEC 27001:2013** A.6.1.1

Function	Category	Subcategory	Informative References
	adequate awareness of anomalous events.		• **NIST SP 800-53 Rev. 4** CA-2, CA-7, PM-14
		DE.DP-2: Detection activities comply with all applicable requirements	• **ISA 62443-2-1:2009** 4.4.3.2 • **ISO/IEC 27001:2013** A.18.1.4 • **NIST SP 800-53 Rev. 4** CA-2, CA-7, PM-14, SI-4
		DE.DP-3: Detection processes are tested	• **COBIT 5** APO13.02 • **ISA 62443-2-1:2009** 4.4.3.2 • **ISA 62443-3-3:2013** SR 3.3 • **ISO/IEC 27001:2013** A.14.2.8 • **NIST SP 800-53 Rev. 4** CA-2, CA-7, PE-3, PM-14, SI-3, SI-4
		DE.DP-4: Event detection information is communicated to appropriate parties	• **COBIT 5** APO12.06 • **ISA 62443-2-1:2009** 4.3.4.5.9 • **ISA 62443-3-3:2013** SR 6.1 • **ISO/IEC 27001:2013** A.16.1.2 • **NIST SP 800-53 Rev. 4** AU-6, CA-2, CA-7, RA-5, SI-4
		DE.DP-5: Detection processes are continuously improved	• **COBIT 5** APO11.06, DSS04.05 • **ISA 62443-2-1:2009** 4.4.3.4 • **ISO/IEC 27001:2013** A.16.1.6 • **NIST SP 800-53 Rev. 4**, CA-2, CA-7, PL-2, RA-5, SI-4, PM-14

Function	Category	Subcategory	Informative References
RESPOND (RS)	**Response Planning (RS.RP):** Response processes and procedures are executed and maintained, to ensure timely response to detected cybersecurity events.	**RS.RP-1:** Response plan is executed during or after an event	• **COBIT 5** BAI01.10 • **CCS CSC** 18 • **ISA 62443-2-1:2009** 4.3.4.5.1 • **ISO/IEC 27001:2013** A.16.1.5 • **NIST SP 800-53 Rev. 4** CP-2, CP-10, IR-4, IR-8
	Communications (RS.CO): Response activities are coordinated with internal and external stakeholders, as appropriate, to include external support from law enforcement agencies.	**RS.CO-1:** Personnel know their roles and order of operations when a response is needed	• **ISA 62443-2-1:2009** 4.3.4.5.2, 4.3.4.5.3, 4.3.4.5.4 • **ISO/IEC 27001:2013** A.6.1.1, A.16.1.1 • **NIST SP 800-53 Rev. 4** CP-2, CP-3, IR-3, IR-8
		RS.CO-2: Events are reported consistent with established criteria	• **ISA 62443-2-1:2009** 4.3.4.5.5 • **ISO/IEC 27001:2013** A.6.1.3, A.16.1.2 • **NIST SP 800-53 Rev. 4** AU-6, IR-6, IR-8
		RS.CO-3: Information is shared consistent with response plans	• **ISA 62443-2-1:2009** 4.3.4.5.2 • **ISO/IEC 27001:2013** A.16.1.2 • **NIST SP 800-53 Rev. 4** CA-2, CA-7, CP-2, IR-4, IR-8, PE-6, RA-5, SI-4
		RS.CO-4: Coordination with stakeholders occurs consistent with response plans	• **ISA 62443-2-1:2009** 4.3.4.5.5 • **NIST SP 800-53 Rev. 4** CP-2, IR-4, IR-8
		RS.CO-5: Voluntary information sharing occurs with external stakeholders to achieve broader cybersecurity situational awareness	• **NIST SP 800-53 Rev. 4** PM-15, SI-5
	Analysis (RS.AN): Analysis is conducted to ensure adequate response and support recovery activities.	**RS.AN-1:** Notifications from detection systems are investigated	• **COBIT 5** DSS02.07 • **ISA 62443-2-1:2009** 4.3.4.5.6, 4.3.4.5.7, 4.3.4.5.8 • **ISA 62443-3-3:2013** SR 6.1 • **ISO/IEC 27001:2013** A.12.4.1, A.12.4.3, A.16.1.5 • **NIST SP 800-53 Rev. 4** AU-6, CA-7, IR-4, IR-

Function	Category	Subcategory	Informative References
			5, PE-6, SI-4
		RS.AN-2: The impact of the incident is understood	• **ISA 62443-2-1:2009** 4.3.4.5.6, 4.3.4.5.7, 4.3.4.5.8 • **ISO/IEC 27001:2013** A.16.1.6 • **NIST SP 800-53 Rev. 4** CP-2, IR-4
		RS.AN-3: Forensics are performed	• **ISA 62443-3-3:2013** SR 2.8, SR 2.9, SR 2.10, SR 2.11, SR 2.12, SR 3.9, SR 6.1 • **ISO/IEC 27001:2013** A.16.1.7 • **NIST SP 800-53 Rev. 4** AU-7, IR-4
		RS.AN-4: Incidents are categorized consistent with response plans	• **ISA 62443-2-1:2009** 4.3.4.5.6 • **ISO/IEC 27001:2013** A.16.1.4 • **NIST SP 800-53 Rev. 4** CP-2, IR-4, IR-5, IR-8
	Mitigation (RS.MI): Activities are performed to prevent expansion of an event, mitigate its effects, and eradicate the incident.	**RS.MI-1:** Incidents are contained	• **ISA 62443-2-1:2009** 4.3.4.5.6 • **ISA 62443-3-3:2013** SR 5.1, SR 5.2, SR 5.4 • **ISO/IEC 27001:2013** A.16.1.5 • **NIST SP 800-53 Rev. 4** IR-4
		RS.MI-2: Incidents are mitigated	• **ISA 62443-2-1:2009** 4.3.4.5.6, 4.3.4.5.10 • **ISO/IEC 27001:2013** A.12.2.1, A.16.1.5 • **NIST SP 800-53 Rev. 4** IR-4
		RS.MI-3: Newly identified vulnerabilities are mitigated or documented as accepted risks	• **ISO/IEC 27001:2013** A.12.6.1 • **NIST SP 800-53 Rev. 4** CA-7, RA-3, RA-5
	Improvements (RS.IM): Organizational response activities are improved by incorporating lessons learned from current and previous detection/response activities.	**RS.IM-1:** Response plans incorporate lessons learned	• **COBIT 5** BAI01.13 • **ISA 62443-2-1:2009** 4.3.4.5.10, 4.4.3.4 • **ISO/IEC 27001:2013** A.16.1.6 • **NIST SP 800-53 Rev. 4** CP-2, IR-4, IR-8
		RS.IM-2: Response strategies are updated	• **NIST SP 800-53 Rev. 4** CP-2, IR-4, IR-8
RECOVER (RC)	**Recovery Planning (RC.RP):** Recovery processes and procedures are executed and maintained to ensure timely	**RC.RP-1:** Recovery plan is executed during or after an event	• **CCS CSC** 8 • **COBIT 5** DSS02.05, DSS03.04 • **ISO/IEC 27001:2013** A.16.1.5

Function	Category	Subcategory	Informative References
	restoration of systems or assets affected by cybersecurity events.		• **NIST SP 800-53 Rev. 4** CP-10, IR-4, IR-8
	Improvements (RC.IM): Recovery planning and processes are improved by incorporating lessons learned into future activities.	**RC.IM-1:** Recovery plans incorporate lessons learned	• **COBIT 5** BAI05.07 • **ISA 62443-2-1:2009** 4.4.3.4 • **NIST SP 800-53 Rev. 4** CP-2, IR-4, IR-8
		RC.IM-2: Recovery strategies are updated	• **COBIT 5** BAI07.08 • **NIST SP 800-53 Rev. 4** CP-2, IR-4, IR-8
	Communications (RC.CO): Restoration activities are coordinated with internal and external parties, such as coordinating centers, Internet Service Providers, owners of attacking systems, victims, other CSIRTs, and vendors.	**RC.CO-1:** Public relations are managed	• **COBIT 5** EDM03.02
		RC.CO-2: Reputation after an event is repaired	• **COBIT 5** MEA03.02
		RC.CO-3: Recovery activities are communicated to internal stakeholders and executive and management teams	• **NIST SP 800-53 Rev. 4** CP-2, IR-4

Information regarding Informative References described in Appendix A may be found at the following locations:

- Control Objectives for Information and Related Technology (COBIT): http://www.isaca.org/COBIT/Pages/default.aspx
- Council on CyberSecurity (CCS) Top 20 Critical Security Controls (CSC): http://www.counciloncybersecurity.org
- ANSI/ISA-62443-2-1 (99.02.01)-2009, *Security for Industrial Automation and Control Systems: Establishing an Industrial Automation and Control Systems Security Program*: http://www.isa.org/Template.cfm?Section=Standards8&Template=/Ecommerce/ProductDisplay.cfm&ProductID=10243
- ANSI/ISA-62443-3-3 (99.03.03)-2013, *Security for Industrial Automation and Control Systems: System Security Requirements and Security Levels*: http://www.isa.org/Template.cfm?Section=Standards2&template=/Ecommerce/ProductDisplay.cfm&ProductID=13420
- ISO/IEC 27001, *Information technology -- Security techniques -- Information security management systems -- Requirements*: http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=54534
- NIST SP 800-53 Rev. 4: NIST Special Publication 800-53 Revision 4, *Security and Privacy Controls for Federal Information Systems and Organizations*, April 2013 (including updates as of January 15, 2014). http://dx.doi.org/10.6028/NIST.SP.800-53r4.

Mappings between the Framework Core Subcategories and the specified sections in the Informative References represent a general correspondence and are not intended to definitively determine whether the specified sections in the Informative References provide the desired Subcategory outcome.

Appendix B: Glossary

This appendix defines selected terms used in the publication.

Category	The subdivision of a Function into groups of cybersecurity outcomes, closely tied to programmatic needs and particular activities. Examples of Categories include "Asset Management," "Access Control," and "Detection Processes."
Critical Infrastructure	Systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on cybersecurity, national economic security, national public health or safety, or any combination of those matters.
Cybersecurity	The process of protecting information by preventing, detecting, and responding to attacks.
Cybersecurity Event	A cybersecurity change that may have an impact on organizational operations (including mission, capabilities, or reputation).
Detect (function)	Develop and implement the appropriate activities to identify the occurrence of a cybersecurity event.
Framework	A risk-based approach to reducing cybersecurity risk composed of three parts: the Framework Core, the Framework Profile, and the Framework Implementation Tiers. Also known as the "Cybersecurity Framework."
Framework Core	A set of cybersecurity activities and references that are common across critical infrastructure sectors and are organized around particular outcomes. The Framework Core comprises four types of elements: Functions, Categories, Subcategories, and Informative References.
Framework Implementation Tier	A lens through which to view the characteristics of an organization's approach to risk—how an organization views cybersecurity risk and the processes in place to manage that risk.
Framework Profile	A representation of the outcomes that a particular system or organization has selected from the Framework Categories and Subcategories.
Function	One of the main components of the Framework. Functions provide the highest level of structure for organizing basic cybersecurity activities into Categories and Subcategories. The five functions are Identify,

	Protect, Detect, Respond, and Recover.
Identify (function)	Develop the organizational understanding to manage cybersecurity risk to systems, assets, data, and capabilities.
Informative Reference	A specific section of standards, guidelines, and practices common among critical infrastructure sectors that illustrates a method to achieve the outcomes associated with each Subcategory.
Mobile Code	A program (e.g., script, macro, or other portable instruction) that can be shipped unchanged to a heterogeneous collection of platforms and executed with identical semantics.
Protect (function)	Develop and implement the appropriate safeguards to ensure delivery of critical infrastructure services.
Privileged User	A user that is authorized (and, therefore, trusted) to perform security-relevant functions that ordinary users are not authorized to perform.
Recover (function)	Develop and implement the appropriate activities to maintain plans for resilience and to restore any capabilities or services that were impaired due to a cybersecurity event.
Respond (function)	Develop and implement the appropriate activities to take action regarding a detected cybersecurity event.
Risk	A measure of the extent to which an entity is threatened by a potential circumstance or event, and typically a function of: (i) the adverse impacts that would arise if the circumstance or event occurs; and (ii) the likelihood of occurrence.
Risk Management	The process of identifying, assessing, and responding to risk.
Subcategory	The subdivision of a Category into specific outcomes of technical and/or management activities. Examples of Subcategories include “External information systems are catalogued,” “Data-at-rest is protected,” and “Notifications from detection systems are investigated.”

Appendix C: Acronyms

This appendix defines selected acronyms used in the publication.

CCS	Council on CyberSecurity
COBIT	Control Objectives for Information and Related Technology
DCS	Distributed Control System
DHS	Department of Homeland Security
EO	Executive Order
ICS	Industrial Control Systems
IEC	International Electrotechnical Commission
IR	Interagency Report
ISA	International Society of Automation
ISAC	Information Sharing and Analysis Center
ISO	International Organization for Standardization
IT	Information Technology
NIST	National Institute of Standards and Technology
RFI	Request for Information
RMP	Risk Management Process
SCADA	Supervisory Control and Data Acquisition
SP	Special Publication

APPENDIX B: THE THEORETICAL MODEL -- FROM THE VIEWPOINT OF PI-CALCULUS -- FOR INTERACTION AMONG SOCIALLY-AWARE PURPOSEFUL AGENTS

For simplicity, we have directly borrowed an excerpt, from http://www.ebpml.org/pi-calculus.htm, for the theoretical model -- from the viewpoint of pi-calculus -- for interaction among socially-aware purposeful agents.

The ubiquity of TCP/IP and the Internet has enabled many systems to communicate with their environment with great ease. Such interactive systems are actually becoming the norm. Surprisingly, most of the work to model these categories of systems has started fairly recently when compared to the theory of sequential algorithmic processes (lambda-calculus) which is the foundation of all programming languages. Actually, the first steps of lambda-calculus can be traced back to the 1600s with the work of Mathematician and Philosopher, Blaise Pascal, who designed and built the first (mechanical) calculator.

The lambda -calculus theory is about modelling systems which have no or little interactions with their environment. On the contrary, the pi-calculus theory developed by Robin Milner in the late 1980s is about modelling concurrent communicating systems. This theory also takes into account the notion of "mobility" which can either be physical or, as in the case of B2B, virtual (movement of links between systems). I think we can actually relate the mobility to the notion of "change": change of business partner, business document format, capabilities, etc – any modification of an existing relationship between two companies may be associated with mobility.

As a side note, pi-calculus is the foundation of two of the main Process Markup Languages: BPML from the BPMI consortium and XLANG (now BPEL4WS) from Microsoft, which we will study at the end of this chapter.

*At a high level, a company can be considered to be a very large automaton whose logical **state** consists of gigabytes or terabytes of data, and physical state is made of the raw materials, manufactured goods, people, and money under its control. Its state is strictly bounded in the sense that it is owned and accessible in its entirety from the corporation, but hidden from any other corporation. A company can change its state by initiating an **action** (ship an order, pay a supplier, …). When another corporation wants to change or query this state it is done via an **interaction.** Interactions usually trigger some internal actions based on business rules, which enable the corporation to ultimately be in a state which is consistent with the one of its business partners.*

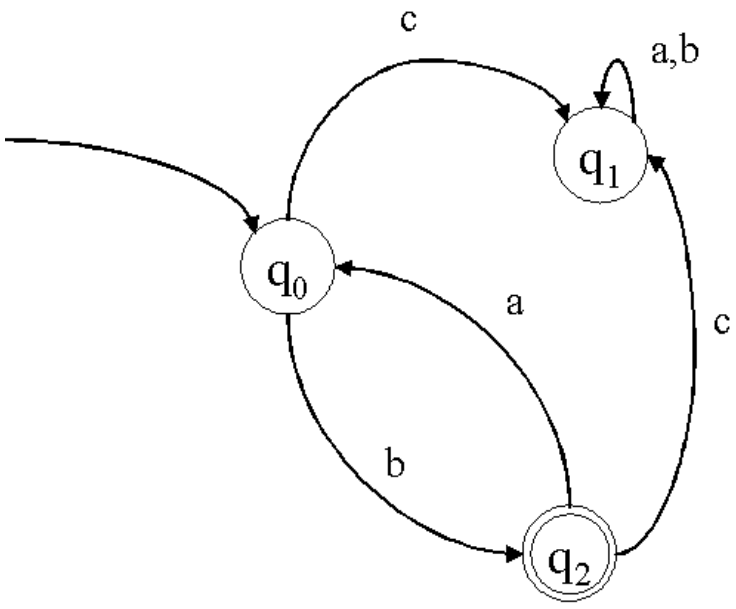
*The company's **actions**, when executed, the transition from one state to another. Interactions and actions, when assembled together, form the enterprise business processes. Both the number of **actions** and **states** can be large for any given corporation. However, they are both finite.*

Let's look at more details at an automaton. The classical theory, as the starting point of Milner's theory, specifies that an automation over a set of actions ***Act*** *has four ingredients:*

- *A set of states* $\mathbf{Q} = \{q_0, q_1, \ldots\}$
- *A start state* q_0
- *A set of transitions which are triplets (q,a,q') members of* $\mathbf{Q \times Act \times Q}$
- *A subset* $\mathbf{F}$ *of* $\mathbf{Q}$ *called the accepting states*

In theory, a business is deterministic, thus, will obey the rule that for each pair of state and action (q,a) there is at most one transition (q,a,q').

An automaton can be represented by a directed graph as shown below. States are represented in circles ($q_0, q_{1\ldots}$*) transitions are represented as arrows (*$t = q_0$ *.c.* q_1 *) and accepting states are represented with a double circle:*



This model can be extended to introduce the notion of events and conditions, which may act as a ***guard*** *to an action. Actions may be automatic; when one reaches a state* q_i *an action "a" occurs without any other pre-conditions. In other cases, a "condition" may decide whether the action "a" or "b" will happen, again automatically. Lastly, an event, sometimes combined with a condition, may trigger an action (Event Condition Action model), which in turn will transition the automaton from a state to another.*

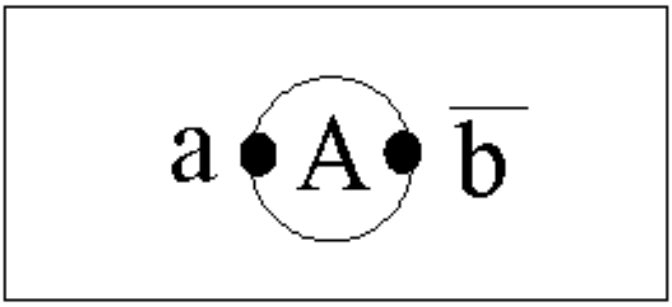
When the number of potential states is large this diagram becomes impractical and is often replaced by an activity diagram, just like the UML activity diagram. This diagram is drawn from

a different perspective. It does not show the specific states the automaton may take but rather the controlled succession of activities (that is, actions) that may occur within a corporation. State-transition or activity diagrams are often referred to as processes or sequential processes.

When two corporations are engaging in B2B activities, they are each running their (internal) sequential process concurrently. These two processes must interact to reflect commitments, transfer of economic resources, and many other aspects of the business activity shared between the two business partners.

This causes the actions of a given corporation to be divided into two different sets: those which are externally observable and those which are internal.

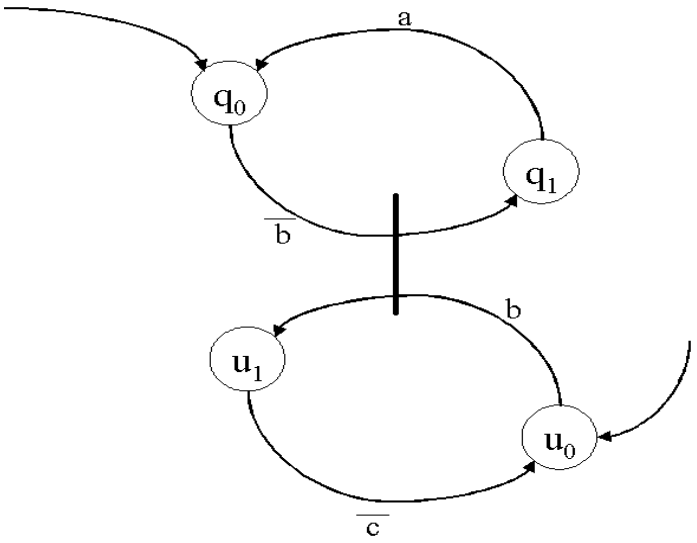
*At this point, the automaton **A** (that is, the corporation) is considered as a black box and the externally observable actions can be represented with the following notation (in this case only two of them):*



a and b are called labeled ports. Each complementary pair (b, b) of ports represents a means of interaction between two automata. These are the points of synchronization between the automata.

This graph is called a flowgraph. While the transition graph depicts the dynamic properties of a system, a flowgraph depicts the structure of the system, in other words, the relationships between its components. An automaton can have any number of labelled ports, and a port may bear any number of arcs directed to any number of automata.

If we look at a global picture we see that the two automata A and B are running with no particular dependence except that any action b from B must be synchronized with an action from B from A:



The synchronization is represented by a shared transition between their state-transition graphs. This notion of shared transition was first introduced by Carl-Adam Petri in his theory of Automata. The corresponding graphs have been known as Petri nets.

Let's draw some conclusions from this very short exposure to the p-calculus theory. First and foremost, there is no need to expose the details of the processes to model their interactions. It is enough to focus on the externally observable actions. Nothing prevents a corporation from exposing as much of its internal actions as it wishes (sometimes to obey regulatory requirements such as the ones in the aerospace or pharmaceutical industry, or yet to comply with standards such as ISO 9000), but it is completely separate from the specification of interactions. These internal actions do not become external once they are exposed, they remain internal since they are not part of the interaction. This is the ultimate goal: providing a shared view of the interactions regardless of the actions that lead to any particular interaction. Most companies consider their internal actions as their core assets and therefore are very reluctant to expose them.

Second, interactions are solely supported by the actions of the two concurrent automata involved. In particular, interactions do not require a third automaton which role would be to manage them unless chosen by design (such as a broker, or a market place between buyers and suppliers in typical B2B topologies).

Last, a set of enterprise information systems can be viewed as a communicating and mobile automata. Inside a corporation, they can be aggregated to form a single logical automaton. Once we reach the boundary of a corporation, automata may no longer be composed since corporations do not share any state but rather synchronize their respective states when they communicate.

The pi-calculus theory is far more elaborate than what was presented in this section. Our goal here was to introduce a few concepts that will be helpful in building the big picture and position PMLs and ebXML together.

