Leader-Driven Supply Chain Cybersecurity Framework

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Abstract

Supply chains (SC) often span multiple cultures, countries, and time zones. There are two general aspects of security concern in an SC: 1) the products and assets, 2) the information technology (IT). SCs can achieve higher operational efficiency if the entities involved are highly connected since the rapid transmission of information helps SC participants be agile and adaptable. A key requirement of highly interconnected systems is a strong level of overall cybersecurity. We suggest that enhancing individual partners' security alone may not help improve the SC cybersecurity; it requires the powerful member of the SC to take leadership in cybersecurity efforts. We propose a framework for the leader in the SC that involves: 1) supplier/member selection; and 2) continuous training, development, and risk assessment of SC members from a cybersecurity perspective. An internet of things (IoT)-based use case is provided to expound on the presented ideas.

Keywords: Supply Chain, Cybersecurity, Framework, Powerful Member

1. INTRODUCTION

The National Institute of Standards and Technology (NIST) states that:

> Supply chains are complex, globally distributed, and interconnected sets of resources and processes between multiple levels of organizations. Supply chains begin with the sourcing of products and services and extend from the design, development, manufacturing, processing, handling, and delivery of products and services to the end user (NIST, 2018b, p. 15).

Supply Chains (SC) consist of entities and their resources which work for the common objective of matching supply with customer demand. The entities in an SC include suppliers,

manufacturers, wholesalers/distributors, and retailers.

SCs that exclusively focus on speed and costs often break down over time; to be resilient and effective, SCs require agility, adaptability, and alignment (Lee, 2004). To accommodate sudden changes in supply and demand, SCs must be agile. To be adaptable, the SC partners should establish long-term relationships and use technology effectively. Being adaptable helps SCs respond to market changes. Collaboration among SC members results in better alignment. Thus, for SCs to work efficiently, the entities must share information on a timely basis, adapt new technology as needed, and have long-term relationships.

There are power asymmetries in SCs (Munson, Rosenblatt, & Rosenblat, 1999). Certain characteristics can give organizational power of one SC member over the others, e.g. a partner has reward power if it can help other SC members achieve their goals. Power types include expert power, referent power, coercive power, and legitimate power. For example, Walmart has huge financial clout and can require its suppliers to do packaging, RFID tagging, and delivery in the way that best suits Walmart, even if some suppliers would have to operate in a suboptimal way. Often the power of one member is sufficiently transcendent that the SC is recognized by that member's name, e.g. Walmart, Target, Boeing, etc. We will generically refer to the partner with the most organizational power as the *powerful member*. The terms leader and powerful member are equivalent in this context, and we will use powerful member from this point forward.

A cybersecurity disruption to any partner can cause dysfunction along the entire SC. Securing the information and information technology (IT) along the SC is extremely difficult given the degree of complexity involved and suggests several questions:

- Who has overall responsibility for SC cybersecurity?
- What do those responsibilities entail?
- How would a cybersecurity risk assessment of the SC be done by that leader?

As we will discuss in Section 2, the SC member with the greatest organizational power has an important role to play in SC cybersecurity. That role involves including cybersecurity considerations when selecting new SC members and maintaining a healthy SC ecosystem. Cybersecurity-specific risk assessments involve considerations of people, process, and technology.

Figure 1, depicts a stylized SC model. Products/material flow (solid, red arrows) from upstream to downstream (product returns, if any, flow in the opposite direction). Money and information flow (dotted, gold, two-headed arrows) both upstream and downstream. To facilitate the communications and sharing of information SC entities use both internal and external cyber technologies. These systems link the various partners in an SC forming a chain of cyber-physical systems.

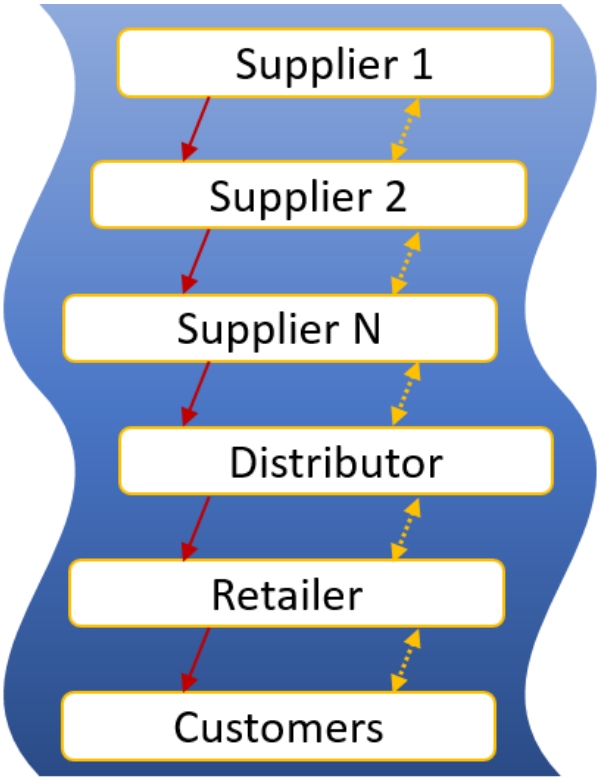

Figure 1 – SC stylized diagram

SC security encompasses both the physical systems (products/assets) and the information technology (IT). Smith, et al., identify the cyber system portion of SCs as a network of IT infrastructures used to connect SC partners and further define

> Supply Chain Information Security Risk (SCISR) as degradation or disruption to a supply chain's infrastructure or structural resources resulting from the successful exploitation of IT vulnerabilities by threats within an organization, within the supply chain network, or in the external environment (Smith, Watson, Baker, & Pokorski, 2007).

In this research, we examine the SCISR in the context of cybersecurity risk management.

There have been many reports of large-scale cybersecurity incidents. Big and small firms alike fall victim to cybersecurity breaches. Mulligan & Schneider report that several past cybersecurity doctrines such as prevention, risk management, and deterrence through accountability did not bear fruit (Mulligan & Schneider, 2011). They recommend viewing cybersecurity as a collective interest similar to public health and suggest that incentive mechanisms must be in place to prompt system developers, operators, and users to improve information system security.

We suggest that for the cybersecurity risk assessment and management to succeed, the powerful member of the SC must take initiative. The other SC members (non-powerful members – note: we use this term to differentiate only, not to imply that the other members have no power per se) are often smaller firms that do not possess the same resources to conduct cybersecurity activities to protect their cyber systems from cyber threats as their powerful member partner.
The vulnerabilities introduced to the SC ecosystem by the least cybersecurity-capable companies weaken the cybersecurity posture of the entire SC since the chain is only as strong as the weakest link. A rigorous analysis of potential SC partners before selection is essential. After selection, the contracts between SC partners need to detail the management of third-party risk in addition to other SC requirements. The Department of Defense's (DoD) Cybersecurity Maturity Model Certification (CMMC) framework addresses vendor accreditation for cybersecurity and helps the DoD determine if the contractors are doing their due diligence protecting the sensitive data that resides on their networks.

In this paper, we are introducing a framework that will help businesses with SC partner selection and management that will reduce the risk of cyber-attacks on SC partners' cyber systems. An important part of the management is continuous risk assessment done by each SC player in the ecosystem, for example, the powerful member does it for first-tier suppliers and vendors; those suppliers do it for their first-tier members; etc. Our framework proposes guidelines on how the powerful member manages the risk assessment process to mitigate the risks in the SC to an acceptable level.

As shown in Figure 1, SC entities are connected by information flow that mainly happens using Electronic Data Interchanges (EDI). Information flow occurs within the company as well as between partners. Thus, properly securing both the internal and external cyber systems is essential. IT systems have been used for decades to automate, streamline, and transform business processes. With cyber systems capturing internal and external business processes, the cybersecurity risks to these systems can be as significant as the financial risks for businesses. The failure to protect the systems could lead to loss of revenue, reputation, and customers. With emerging technologies being integrated into the industrial processes, we are now in the era of Industry 4.0, which is enabled by Artificial Intelligence, Big Data Analytics, Autonomous Robots, Horizontal and Vertical Integration, Internet of Things, Augmented Reality, Additive Manufacturing, Cloud, and Cybersecurity (www.bcg.com). As empowering as these technologies are for businesses, they make the cyber-systems more complex. The more complex they are, the more vulnerable they are.

Examples of interconnected IT systems for the sake of efficiency abound. Walmart's Retaillink system enables suppliers to successfully support Vendor Managed Inventory initiatives. Through this system, the suppliers can see the store-level inventory at any time. Target gives access rights to HVAC vendors to remotely monitor the energy consumption in its network. Lean manufacturing systems require firms to carry as little inventory as possible to support a production schedule. The raw material suppliers have access to shop-floor inventory levels to support Just-in-Time production. It is imperative that the professionals who manage the cyber SC systems have a well-established risk management system in place. The interdependencies between SC partners create additional attack vectors that need to be addressed. A breach that leads to data theft or other unauthorized activity in the systems of any SC component could potentially compromise data of the other SC players.

The paper is organized as follows. In Section 2 we propose a framework for SC cybersecurity. Section 3 provides a short use-case. Our conclusion remarks are in Section 4.

2. CYBERSECURITY FRAMEWORK FOR SUPPLY CHAIN STAKEHOLDERS

2.1 Building the Framework

Suppliers are integral to the success of SC profitability. As discussed above, they also play an important role in keeping the SC secure. The

Japanese philosophies of manufacturing like Just-in-Time and Toyota Production System view suppliers as long-term partners. Hence, it is critical to identify the right suppliers to join the SC as partners. Building a long-term relationship not only helps the SC meet customer demand effectively, but it also helps secure the SC. Knowing that there is a long-term association with the SC powerful member, the other partners will be more willing to adopt process and technology recommendations to secure the SC.

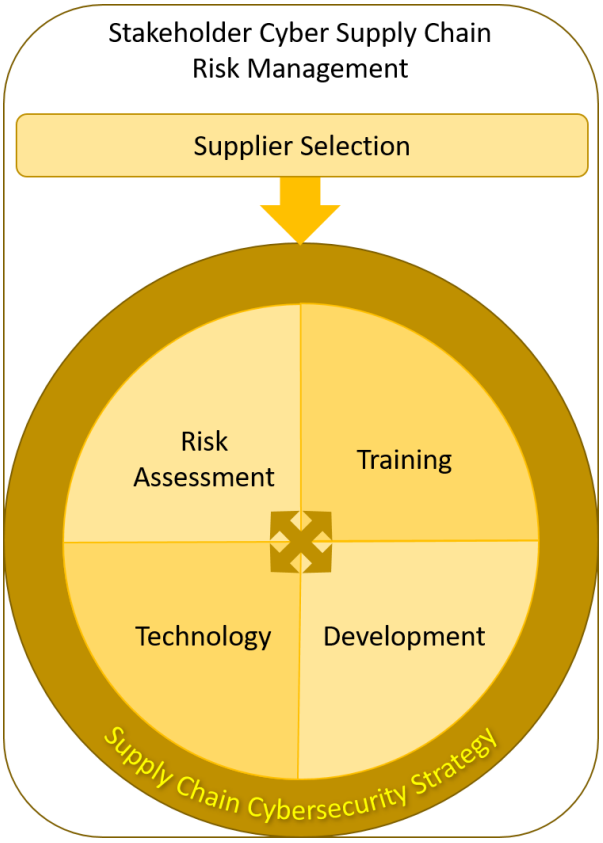

Figure 2 – Framework for Stakeholder Cyber Supply Chain Risk Management (SC-SCRM)

NIST's Cyber Supply Chain Risk Management (C-SCRM) program started in 2008. On the program website, it defines C-SCRM as "the process of identifying, assessing, and mitigating the risks associated with the distributed and interconnected nature of IT/OT [information and operational technology] products and service supply chains" (NIST, 2020). Within NIST's Framework for Improving Critical Infrastructure (FICI), it elaborates that C-SCRM is

> the set of activities necessary to manage cybersecurity risk associated with external parties. More specifically, cyber SCRM addresses both the cybersecurity effect an organization has on external parties and the cybersecurity effect external parties have on an organization (NIST, 2018b, p. 16).

It goes on to explicitly state that the examples provided for how it can be used "are not intended to address C-SCRM comprehensively," thus leaving room for flexible use and extension by practitioners. Our proposed framework is complementary to and fits within the larger FICI and is currently called Stakeholder Cyber Supply Chain Risk Management (SC-SCRM). The elements of the framework are shown in Figure 2.

The framework has two main parts, the Supplier Selection process and what happens after a supplier is selected to become a SC member which is comprised of four key components: Training, Development, Technology, and Risk Assessment (TDTR); all informed by the Supply Chain Cybersecurity Strategy (SCCS). Readers familiar with concepts like Kaizen (Imai, 1986) may find it helpful to think about the TDTR in the same terms. The SC powerful member can lead SC-SCRM with well-established TDTR components for SC members and by integrating a sound SCCS. The SCCS should be primarily derived from the goals of the powerful member, but with an eye towards synergistic benefit to all SC members. Below, we explain the framework in more detail.

2.2 Supplier Selection Process

The supplier selection process is pivotal in ensuring a working SC-SCRM. To get to these details, we will need first to briefly run through the broad strokes of the larger framework encompassing SC-SCRM.

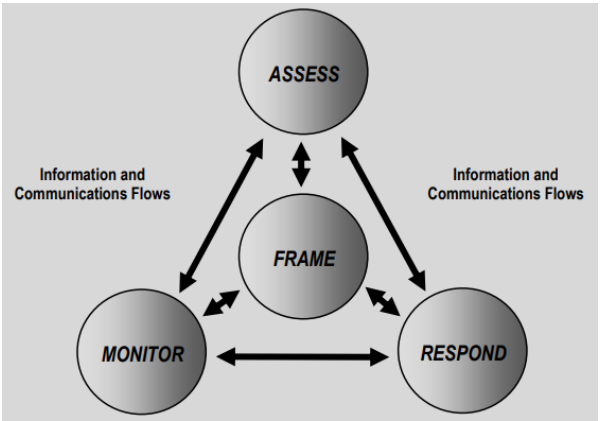

Figure 3 – NIST Risk Management Process (NIST, 2011, p. 8)

The risk management process (RMP) has variously been defined by many organizations

such as NIST and the International Standards Organisation (ISO). NIST enumerates four components of the RMP as follows (NIST, 2011):

- frame risk – establish the context for risk-based decisions
- assess risk
- respond to risk
- monitor risk, continuously over time

The NIST RMP and information/communication flows among the various components are depicted in Figure 3.

Within NIST's FICI, the framework core expands on the above-mentioned elements to enumerate five functions: Identify, Protect, Detect, Respond, and Recover (Figure 4).

Figure 4 – Five Functions of NIST's Framework for Improving Critical Infrastructure (NIST, 2018a)

Further, they enumerate four implementation tiers to "provide context on how an organization views cybersecurity risk and the processes in place to manage that risk" (NIST, 2018, p. 8). These tiers range from Partial (Tier 1), which is informal and reactive, to Adaptive (Tier 4), which is agile and risk-informed, and are briefly summarized as follows:

Tier 1, Partial. Cybersecurity risk is managed in an ad hoc/reactive manner; practices are not formalized; generally unaware of cyber SC risks of the products/services provided and used.

Tier 2, Risk Informed. Cybersecurity risk management practices are approved by management; practices may not be organizational-level policy; generally aware of cyber SC risks, but does not act consistently or formally.

Tier 3, Repeatable. Cybersecurity risk management practices are formally approved and organizational policy; generally aware of cyber SC risks and acts formally upon the risks.

Tier 4, Adaptive. Cybersecurity risk management practices are adaptive and informed by previous and current cybersecurity activities; aware of SC risks, contributes to the SC community's understanding of risks; communicates proactively to maintain strong SC relationships.

A firm must consider which Tier a potential SC partner needs to occupy before it could become a SC member. This is somewhat analogous to setting ISO certification as a basic qualifier to be a supplier. To mitigate risks to acceptable levels, if the determined prerequisite Tier is lower than Tier 4, a road map for a SC member to gradually reach Tier 4 would minimize the exposure factor of the SC ecosystem. It is important to note that tiers assist in risk management of the power player and do not correspond to the maturity levels (NIST, 2018b).

An extensive list of criteria can be considered during a supplier selection process (Thanaraksakul & Phruksaphanrat, 2009). The list is quite comprehensive but can be broadly classified into the five perspectives of (i) Financial (ii) Customer (iii) Internal Business Process, (iv) Learning and Growth, (v) Corporate Social Responsibility. The financial aspect is related to the ability of a vendor to have long term profitability. The customer aspect is related to the ability of the vendor to provide goods and services quickly as the firm's customer requirement changes. The internal business process relates to the vendor's ability to provide quality products and services at the right time and in the right quantities. The learning and growth measure is the flexibility of the vendor to adapt to changing market conditions. And, the corporate social responsibility is the ability of the vendor to be a good citizen company adhering to legal, societal, and environmental commitments.

In addition to the factors listed above, we propose that cybersecurity has reached a sufficient level of importance, that a supplier selection process should explicitly incorporate criteria relevant to the key layers of cybersecurity: people, processes, and technology. In this three-layered approach, people refers to having cybersecurity

experts with appropriate qualifications in key positions as well as periodically training employees and testing their knowledge in cybersecurity awareness. Processes are there to ensure that SC risk tolerance and business objectives are aligned. The technology layer refers to having proper technology and tools in place, and that these tools are utilized in the way that would be aligned with the cybersecurity strategy of the powerful member. A scorecard template is in Table 1 would help to rank potential SC participants. The specific criteria beneath the three key parts are examples and not meant to be comprehensive or specifically required in keeping with the spirit of the flexibility of FICI.

SC-SCRM Evaluation Scorecard	
People	**Tier**
CISO	
Network Security Engineer	
Security Analyst	
Etc. …	
Processes	**Tier**
Cyber Incident Response Plan	
Endpoint Monitoring	
Vulnerability Management	
System Update Strategy	
Etc. …	
Technology	**Tier**
Identity Management	
Email Security	
Firewalls	
Access Control	
Security Log Maintenance	
Etc. …	

Table 1 – Cybersecurity-focused Evaluation Scorecard Template for potential supply chain participants

Organizations will want to craft the scorecard with items of specific importance to them and informed by their cybersecurity policy. Good sources for scorecard criteria are the categories and subcategories of the FICI framework core. Evaluating the criteria based on implementation tiers and then summing the result can provide a quantitative manner of comparison where higher scores would indicate a better potential SC partner from a cybersecurity perspective.

2.2 Training

The training component of the framework focuses on the powerful member's strategy on education, training, and awareness of the SC partners in all areas of the selection process: people, processes, and technology. The minimal tier requirement for each SC partner determined by the powerful member provides guidance on the minimal acceptable cyber hygiene levels for the SC ecosystem. Aligned cybersecurity policy and procedures of the SC ecosystem would be a means to make sure that every SC partner maintains the expected minimal cybersecurity posture. The policies and procedures should detail important items like incident handling, incident monitoring, incident response plan, etc. Each SC partner doing periodical audits of their systems and users is necessary for the integrity of the system and user provisions. Any exploits found through the audits need to be addressed by every partner of the supply chain ecosystem with the lead of the power player. Communication in between partners is essential through this process. The policies and procedures should address the management of data and user access for the partners leaving the SC ecosystem.

The training component would address improving the security posture of SC partners. If a partner is at the minimum acceptable tier at selection time, the training, coupled with development process of the framework progressively work towards bringing the partner as close as possible to Tier 4. It is important to note that some supply chain partners may never reach Tier 4 based on their firm size and available resources.

2.3 Development

Supplier development includes activities like site visits and personnel training with the goal of improving the capabilities and performance of the supplier. Since this requires financial investment in suppliers, Talluri, et al. propose optimization models for allocating resources among multiple suppliers to minimize risk and maintain an acceptable level of return (Talluri et al., 2010).

In the context of SC cybersecurity, natural questions to ask are: should the investment be made based on security weakness or should it be done based on the organization's ability to scale up the technological capabilities. Both are important, the management may have to optimize the investment in both areas. The dynamic nature of the market requires the entities to evolve on a continuous basis. The role of the powerful member cannot be emphasized enough to achieve the continuous improvement of the SC. As the business evolves, the organizational goals evolve for the powerful member. When the organizational goals evolve, the cybersecurity strategy evolves as well. This may require that suppliers move up the Tier structure of FICI. The powerful member should take an active role in developing the road map for other members to achieve the required Tier.

2.4 Technology

Industry 4.0 utilizes emerging technologies to improve efficiencies in SCs. Most of the emerging technologies come with unidentified cybersecurity risks. When an emerging technology is introduced to the SC ecosystem, the powerful member should vet the technology and outline the acceptable configuration/use of it for the other partners of the SC before it becomes embedded into the SC.

As an example, when considering embedded automotive network parts, researchers have identified the need to design and implement key security mechanisms to improve the cybersecurity posture of the parts, and, ultimately, the automobiles being produced, specifically: communication encryption, anomaly detection, and embedded software integrity (Studnia et al., 2013). It's likely that this category can be extended to other industries as well, especially where embedded electronic components are used.

One extension is the use of blockchain technology to provide decentralized secure ledgers for SC partners. Blockchain technology is a promising driver of common digital SC standards, but is not currently something that even the largest companies can impose on others and will require real collaboration to make it work end-to-end in a SC (Korpela et al., 2017). As SCs continue to digitize and integrate, many SMBs lack key functionalities (e.g. standards, transaction timestamps, secure information flow) that are already designed into blockchain technology.

There are many benefits that blockchain technology could bring to supply chains, they include:

- tracing the origin (the entire provenance) of the product/process, that is verifiable, thus preventing counterfeits
- improved trust among the members because every member has the same verified information
- improvement in data integrity because any incorrect information can be easily traced to the member who entered the incorrect information
- IoT (Internet of Things) devices can be easily connected to the supply chain and the data is available throughout the supply chain thus ensuring the products conform to the requirements (e.g. pick and pack dates, storage temperatures, transportation routes, etc.)
- financial transactions happen quickly
- helps to achieve JIT production.

The impact of blockchain technology just on reducing counterfeit products could be tremendous. According to a 2018 report, the value of counterfeit goods in 2017 was estimated at $1.2 trillion and is likely to rise 50% to $1.82 trillion by 2020 (Research and Markets, 2017).

2.5 Risk Assessment

Managing SC risk requires a collaborative effort among the members to identify, evaluate, mitigate, and monitor events that may adversely affect the functioning of the SC (Ho et al., 2015). Cybercriminals usually exploit the weakest link in the SC. One study indicates that 23% of SC security incidents involve current partners while 45% involve former partners (PwC, 2014). Hence, the risk management strategies in an SC context must include all partners.

SCs face a myriad of security threats to products/assets as well as information systems. The National Cyber Security Center (NCSC) classifies cybersecurity threats into un-targeted and targeted attacks (NCSC, 2016). Targeted attacks are directed towards a specific entity. Examples include distributed denial of service (DDoS), subverting the supply chain (attacking equipment or software used by the organization), and spear-phishing. Ransomware, phishing, spoofing, and water holing are examples of untargeted attacks as they don't have a specific target. The organizations need to know the weak points in their SCs to ensure a robust risk mitigation strategy (Smith et al., 2007). Ghadge, et al. classify these weak points into three dimensions: technical, human, and physical (Ghadge et al., 2019). Boone suggests that the strength of an SC's defense against cyber threats is only as good as the most susceptible member in the supply chain (Boone, 2017).

Now, we suggest a scorecard for conducting a risk assessment of SC members through the lens of cybersecurity. SC cybersecurity is assessed from the perspective of the SC powerful member.

NIST has defined risk as

> a measure of the extent to which an entity is threatened by a potential circumstance or event, and is typically a function of: (i) the adverse impacts that would arise if the circumstance or event occurs; and (ii) the likelihood of occurrence (NIST, 2012, p. 6).

This definition implies: **impacts * likelihood = risk**

Switching the term order, substituting consequences for the word impacts, and further understanding likelihood as the combination of a threat exploiting a vulnerability (NIST, 2012), we can extrapolate to the well-known formula: **(threat * vulnerability) * consequence = risk**

Driving one of the variables in the formula to zero will make the risk go away; however, a zero value for any variable may well require infinite resources and is generally impractical. Hence, the SC members will generally expend resources in a balanced manner to minimize the value of each of the variables.

Table 2 shows the general structure of the proposed risk assessment matrix template integrating the key layers of cybersecurity within the organization of the powerful member, current SC partners, and former partners.

	Threat	Vulnerability	Consequence	Risk
Organization 1. People 2. Process 3. Technology				
Current Partners 1. People 2. Process 3. Technology				
Former Partners 1. People 2. Process 3. Technology				
			Total Risk	

Table 2 – Risk Assessment Matrix Template

The people aspect ensures that each SC partner employs key, qualified cybersecurity personnel and implements a thorough cybersecurity awareness training program to address one of the biggest threats: insiders. Process evaluation ensures that any changes to SC partner structure do not impact the alignment of that partner within the SC ecosystem. Also, if any changes happen to the powerful member's cybersecurity processes, due to the introduction of new tools for example, the alignment is updated appropriately for each partner. The technology layer ensures that partners update their tools and monitor their use IAW guidelines provided by the powerful member.

The primary risk assessment by the powerful member does not preclude each SC partner also conducting assessments in this manner. The most cybersecurity-mature SC will encourage this and have key personnel meet periodically to more thoroughly evaluate the overall cybersecurity risk of the SC ecosystem.

3. INTERNET OF THINGS (IoT) SUPPLY CHAIN SUPPLIER SELECTION USE CASE

Internet of things (IoT) devices have become ubiquitous and are transforming our way of life. However, the vulnerabilities in the IoT SC have raised serious concerns about the security and trustworthiness of these devices and the components within them. These issues can be further highlighted in the various industries like, healthcare, defense, etc. The IoT SC for these critical infrastructure devices needs to be secured. Modern IoT devices are an amalgamation of various components developed and produced by multiple suppliers and these SCs need to be made secure. A generic IoT technology stack includes components like, endpoints (sensors/actuators), firmware/OS, communication stack (routers, access points, gateways, protocols), cloud servers, client-side applications.

In the above-mentioned framework for the SC supplier selection the scenario would unfold as follows. After receiving specific information as a response to a request for proposals/tenders, the requester will compute a matrix as outlined in Table 1. Each potential supplier will be graded and assigned a numerical score for the various categories of interest enumerated by the SC powerful member within the three categories of people, process, and technology. If a supplier meets the required minimum in each category that supplier qualifies from a cybersecurity perspective as a potential finalist. The matrix will help evaluate each supplier on specific criteria deemed important to the overall SC ecosystem. If multiple suppliers meet the required minimum in each category, they can then be evaluated on attributes other than cybersecurity. A question requiring further study is where cybersecurity should fall in relative importance to other criteria for supplier selection. Once selected a supplier can be further developed by focusing on the personnel training, capability development and investing in secure technology.

4. CONCLUSIONS

Cybersecurity has been attracting a lot of attention for the past 20 years and that attention seems to be only intensifying due to the increasing need for cybersecurity professionals ((ISC)2, 2019). Suggested tools and techniques for dealing with SC cybersecurity has generally lagged other areas as evidenced by NIST not adding a Supply Chain category to the FICI until 2018. SCs are often characterized by power asymmetries. We have argued that the onus of

responsibility for SC cybersecurity falls on the shoulders of the powerful member. Naturally, the question arises as to what role the powerful member plays and to what degree. We suggest that they begin the cybersecurity focus when identifying the right members to include in the SC. To this end, we develop a Stakeholder Cyber Supply Chain Risk Management (SC-SCRM) framework which includes: Supplier Selection and four components intended for use as a continuous improvement process – Training, Development, Technology, and Risk Assessment (TDTR). The TDTR are all informed by the Supply Chain Cybersecurity Strategy (SCCS).

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