Project to Develop an Interoperable Seafood Traceability Technology Architecture: Issues Brief

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Abstract: The Interoperable Seafood Traceability Technology Architecture Issues Brief reflects the growing need to establish a global, secure, interoperable support system for seafood traceability. Establishing effective traceability systems relies on the development of a cohesive and consistent approach to the delivery of information technology capabilities and functions. The ability of business to utilize traceability for commercial gain is heavily influenced by the supply chain in which they operate. The Issues Brief describes factors associated with enterprise-level traceability systems that will impact the design of technology architecture suited to enabling whole chain interoperable traceability. The Brief details why a technology architecture is required, what it means for industry in terms of benefits and opportunities, and how the architecture will translate into practical results. The current situation of many heterogeneous proprietary systems prevents global interoperable traceability from occurring. Utilizing primary research and lessons learned from other industries, the Brief details how the present situation can be addressed. This will enable computerized information systems to communicate syntactically by sharing standardized packages of data. The subsequent stage, semantic interoperability, is achieved by establishing a common language (ontology). The report concludes with a series of recommendations that industry can act upon to design a technology architecture suited to enabling effective global interoperable traceability.

Keywords: architecture, chain, interoperability, seafood, semantic, supply, syntactic, technology, traceability, value

Executive Summary

The ability of businesses to proactively manage risks, reduce costs, and increase revenue rests on the effective sharing of information. Verifying the accuracy and rigor of data exchanged within and between businesses for the purposes of traceability rests on the existence of effective interoperable information systems. Effective interoperability relies on sharing a common technology architecture, in other words a common blueprint or framework, among the systems utilized by businesses operating along a value chain.

The purpose of this Issues Brief is to support the Interoperable Seafood Traceability Technology Architecture Project being led by the Institute of Food Technologists Global Food Traceability Center. The project stems from a growing realization that a need exists to establish a global, secure, interoperable support system for seafood traceability. Establishing an effective global traceability systems relies on the development of a cohesive and consistent approach to the delivery of information technology capabilities and functions. Information technology architecture describes the process of achieving this through the methodical development of a common and coherent series of specifications, models, guidelines, and concepts.

Technology architectures are developed through engaging industry stakeholders in a purposeful dialogue about why the architecture is required, what it means for industry in terms of benefits and opportunities, and how the architecture will translate into practical results. Through this Issues Brief we seek to foster the dialogue, momentum, and activities required to produce the technology architecture required to facilitate global interoperable seafood traceability.

The need to establish a common technology architecture that enables global interoperable seafood traceability is expected to only increase. The seafood industry is increasingly competitive, global, and complex. Consumers are placing greater expectations on suppliers' ability to verify the authenticity, value, sustainability, and safety of seafood that they choose to consume. Regulators are implementing increasingly stringent compliance requirements on industry. Together, these factors result in the need for businesses to develop the ability to manage and mitigate potentially enormous challenges and risks along the entire value chain—with traceability playing an increasingly important role.

The current situation of many heterogeneous proprietary systems prevents global interoperable traceability from occurring. Addressing this situation can only be achieved by establishing a series of standards, protocols, specifications, and guidelines that provide computerized information systems with the ability to communicate effectively by sharing standardized packages of data. The subsequent step in interoperability is establishing a common language (ontology). This enables users to apply information systems to the creation of new knowledge. The ability of businesses to utilize traceability for commercial gain is heavily influenced by the characteristics of the supply chain in which they operate.

This Brief is compiled from the contributions of experts affiliated with industry, government agencies, and nongovernment organizations (NGOs), comprising 4 Technical Advisory Groups (TAGs). Each TAG identified current practices, gaps, and opportunities associated with 4 factors impacting the design and development of a technical architecture suited to facilitating effective global interoperable traceability. The 4 TAGs are: (1) Practices and Processes; (2) Content Mapping; (3) Context Mapping; (4) Engagement and Communication.

The value of traceability or other information and communication technology systems is foremost determined by how it is used by businesses to enable the creation of consumer-recognized value. How businesses utilize information technologies is influenced by the supply chain(s) in which they operate. This Issues Brief therefore begins by describing enterprise-level operational and strategic issues that will impact the design of technology architecture suited to enabling whole-chain interoperable traceability systems. This is followed by discussion of technical and communication-related issues impacting the rigorous exchange of verifiable data. Industries possessing more advanced traceability systems than seafood are then discussed to identify lessons learned that can be utilized in the development of an effective global traceability architecture for the seafood industry.

This project identified factors that must be addressed in designing such a technology architecture. This includes the lack of standardization across the industry. The extent to which the required standardization presently does not occur is evident in the differences in countries' definitions of seafood species. For example, Canada and the United States are important trading partners, yet the Canadian Food Inspection Agency (CFIA) lists nearly 800 species of seafood, while The U.S. Food and Drug Administration (U.S. FDA) lists more than 1,800 species. The similarity between the CFIA and U.S. FDA lists is approximately only 500 species. Such misalignment in the terminology surrounding species leads to compliance challenges and limits traceability effectiveness. Expand this example to differences in species listed by countries worldwide, along with wider implications, such as the terminology used to identify catch location, and the need to establish a common ontology quickly becomes evident.

The complexity of the seafood industry is another significant factor that must be considered in designing a technology architecture for global interoperable traceability. In contrast to industries such as automotive and pharmaceutical, individual seafood firms in the supply chain may range from household-level producers to large multinational corporations. The internal traceability systems range from simple paper-based record keeping and data storage to complex enterprise resource planning (ERP) systems that are automated and integrated with a firm's business operations. This creates major challenges in designing interoperable systems that can interface with such a wide range of technologies. That similar challenges are being overcome in the fresh produce industry, al-

beit at differing paces around the globe, is encouraging. Another characteristic of the seafood industry is the diversity of species, products, and product forms that are harvested, processed, and traded.

Finally, the Issues Brief presents a summary of research findings and implications. Given the critical importance of engaging industry stakeholders in the development of information and communication systems suggests means for engaging the seafood industry in the design of a technology architecture that will enable interoperable traceability in seafood. This Issues Brief concludes with recommendations that can be acted upon to produce a technology architecture designed to enable interoperable seafood traceability. The recommendations relate to the practices and processes of commercial businesses, achieving the standardization necessary to enable interoperable traceability, as well as governance considerations required to protect the commercial interests of businesses' while producing benefits that flow to the wider industry.

Glossary

Catch Location	(if within an Exclusive Economic Zone) A geographic area that is a subset of the FAO Major Fishing Area, and which may be named by country.
CoC	Chain of Custody A formal means of marking the transition points in the supply chain.
COOL	Country of Origin Labeling Refers to the USDA/Agricultural Marketing Service-required labeling for country of harvest or country of substantial transformation prior to entry into the United States, and marking such raw species as farmed or wild-caught.
CTE	Critical Tracking Event point at which product is moved between premises or is transformed, or which is determined to be a point where data capture is necessary to maintain traceability.
EEZ	Exclusive Economic Zone A sea zone prescribed by the United Nations Convention on the Law of the Sea over which a state has special rights regarding the exploration and use of marine resources, including energy production from water and wind.
FAO	Food and Agricultural Organization
GS1 System	The specifications, standards, and guidelines administered by GS1, that function as unique identifiers in the supply chain.
GTIN	(Global Trade Item Number) The format in which GTINs must be represented in the 14-digit reference field (key) in computer files to ensure uniqueness of the identification numbers.
ICES Area	International Council for Exploration of the Sea.
IMO	International Maritime Organization of the United Nations. The global standard-setting authority for the safety, security, and environmental performance of international shipping, whose main role is to create a regulatory framework for the shipping industry that is fair

	and effective, universally adopted, and universally implemented.
Interoperable	The extent to which systems can exchange data, and interpret that shared data.
ITDS	International Trade Data System A single-window, data-entry portal for imports and exports, which must be fully implemented by December 2016, and which is considered by NOAA as interoperable because multiple agencies can view the data.
KDE	Key Data Element Data input required to successfully trace a product and/or its ingredients through all relevant CTEs.
Ontology	In information science, an ontology is a formal naming and definition of the types, properties, and interrelationships between entities that enable a particular type of discourse to occur.
RFMO	Regional Fisheries Management Organizations International organizations formed by countries with fishing interests in an area. Some of them manage all the fish stocks found in a specific area, while others focus on particular highly-migratory species, notably tuna, throughout vast geographical areas.
Semantic Interoperability	The ability of information systems to not only exchange unambiguous data that 2 or more systems understand, but also enable computerized systems to converse in ways that result in a shared sense of meaning and the creation of new knowledge.
Syntactic Interoperability	The ability of 2 or more information technology systems to communicate through a standardized process for packaging and sharing data, the prerequisite for functional interoperability.
Traceability	The ability to track the forward movement of a product through specified stage(s) of the extended supply chain and trace backward the history, application, or location of that product. Results in "the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen and Borit 2013).
Transshipment	To transfer to cargo from one vessel to another while in transit, or in port.
UPC	A barcode symbology used internationally for tracking trade of items at retail, Universal Product Code.

Introduction

The seafood industry is increasingly competitive, global, and complex. Consumers are placing greater expectations on the ability of suppliers to verify the authenticity, value, sustainability, and safety of the seafood they choose to consume. Together these factors result in businesses having to develop the ability to manage and mitigate potentially enormous challenges and risks along the entire value chain. Traceability is playing an increasingly important role in enabling this process to occur. The definition of traceability reflected in this report is: "the ability to access any or all information relating to that which is under consideration, throughout its

entire life cycle, by means of recorded identifications" (Olsen and Borit 2013).

The ability of businesses to proactively manage risks, reduce costs, and increase revenue rests on the effective sharing of information along the value chain.[1] Verifying the accuracy and rigor of data exchanged within and between businesses for the purposes of traceability rests on the existence of effective interoperable information systems. Interoperability relies on the systems utilized by involved businesses sharing a common technology architecture; in other words, a common blueprint or framework. The concept of traceability is generally misunderstood in the seafood sector. If you ask key influencers within the seafood industry about traceability, their responses will focus more on the third-party software solution providers than the actual process of tracing product back to the source. The justification to ensure traceability within the supply chain is even more elusive. Historically, recalls and quality concerns have driven the need to track where a product originated, and who handled it at different touch points throughout the supply chain. In today's world the need to provide assurances to consumers about the exact origin of the products they consume is increasingly important. Businesses must also comply with increasingly stringent compliance requirements. There is a necessity to show that the fishery or farm where a product was sourced meets an acceptable performance level. Fulfilling these needs is impossible without a strong traceability system. The challenge, however, is that there are dozens of systems that have the ability to track and trace product through the system, but their ability to share data with each other as this information flows with the product is almost nonexistent.

The purpose of the GFTC-led Interoperable Seafood Traceability Technology Architecture Project is to address the growing realization of the need to establish a global, secure, interoperable seafood traceability system. Establishing effective global traceability systems relies on the development of a cohesive and consistent approach to the delivery of information technology capabilities and functions. Information technology architecture describes the process of achieving this through methodical development of a common and coherent series of specifications, models, guidelines, and concepts. The present situation of many heterogeneous systems prevents the establishment of global interoperable traceability.

Technology architectures are developed through engaging industry stakeholders in a purposeful dialogue about why the architecture is required, what it means for industry in terms of benefits and opportunities, and how the architecture will translate into practical results. The purpose of this Issues Brief is to help foster the dialogue, momentum, and activities required to produce the technology architecture that will enable global interoperable seafood traceability.

This Brief culminated from the work of 4 Technical Advisory Groups (TAGs), which were established to assist with research, design, and documentation of an initial common blueprint/framework for the technology architecture that can be used for multiple purposes, yet constructed on a set of common requirements. Comprised of experts from industry, government, and NGOs, each TAG identified current practices, gaps, and opportunities associated with 4 factors expected to have an impact on the design and development of a technology architecture suited to

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[1]The term "value chain" is used synonymously with "supply chain" throughout this report to describe the series of businesses and transformation activities that are involved in supplying seafood from the point of harvest (wild-caught or aquaculture) up to purchase of the final product by consumers.

facilitating effective global traceability. The 4 TAGs are: (1) Practices and Processes; (2) Content Mapping; (3) Context Mapping; and (4) Engagement and Communication.

The first 3 TAGs focused on operational and application issues associated with establishing syntactic and semantic interoperable traceability. Syntactic interoperability is the ability of 2 or more systems to exchange basic data. Semantic interoperability is the capabilities that flow from 2 or more systems possessing the ability to meaningfully and accurately interpret data exchanged, through a common language (ontology). Each TAG conducted a literature review, followed by discussion of findings in relation to: (1) the current state of interoperability in global seafood traceability, including gaps that may exist in technical specifications, standards, and other aspects of interoperability; (2) how gaps in commercial capability of traceability systems can be addressed through the development of a common technology architecture; (3) lessons from other industries that can be used to help design an appropriate technology architecture for seafood traceability; and (4) how factors associated with different types of value chains will impact the design of technology architecture. The 4th TAG explored effective means for engaging and communicating with industry during the development of a technology architecture required to enable global interoperable seafood traceability.

As the value of a traceability system is foremost determined by how it is used by businesses to enable the creation of consumer-recognized value, the Issues Brief begins by describing enterprise level operational and strategic issues that will impact the design of technology architecture suited to enabling whole-chain interoperable traceability systems. This is followed by a discussion of technical and communication-related issues affecting the rigorous exchange of verifiable data in the context of the global seafood industry. Research implications that have an impact on the design of a technology architecture and how industry is engaged in the process are then discussed. The Issues Brief concludes with recommendations that will guide the development of a technology architecture suited to enabling global interoperable traceability in seafood.

Practices and Processes

This chapter focuses on the commercial considerations, particularly practices and processes that occur at the level of a firm, that are vital considerations in designing a global traceability architecture. The chapter has 4 main objectives: (1) define the processes and practices used by the seafood industry in managing and using traceability-related information; (2) compare the systems with industries that have developed comprehensive traceability architectures; (3) determine gaps and challenges facing the seafood industry in developing information systems within and across firms; and (4) make recommendations for developing key practices that are vital for developing a successful architecture.

The design and implementation of a global interoperable seafood traceability technology architecture must take into account the structure and behavior of the industry, especially with respect to how seafood firms manage and use information internally and externally. Architectural design must encompass the information needs of a complex and diverse industry and provide value to individual firms as well as entire supply chains. The design must support the evolution of supply chains in using traceability-related information that improves business performance and meets regulatory mandates imposed by government fishery management bodies. The design must also address key information processes and support practices that record, store, analyze, and distribute product information within the firm, as well as across firms.

Key to meeting these traceability-related information needs is understanding the core processes integral to information systems as well as the strategic actions and practices that bring those processes to life. Although the processes defining information technology are fixed and fundamental, the actual practices are highly variable. This is especially true given the seafood industry's diversity in terms of:

1. species and geography,
2. resource management systems,
3. production methods and scale/scope, and
4. supporting economic, technological, and governance "infrastructures."

At both the firm level as well as across supply chains, the range and sophistication of information systems and practices reflect this diversity. Developing the architectural systems and information practices that can embrace this diversity, generate real net-value, and support the evolution of industry needs is the paramount challenge.

To determine both the gaps that need to be bridged, and the opportunities that can be leveraged in establishing a common traceability architecture, it is useful to: (1) determine the potential drivers of whole chain traceability; (2) characterize the generic processes that enable interoperable traceability; (3) discuss the wide range of practices that seafood firms employ that are important for internal and external traceability; and (4) examine inter-firm characteristics that determine the value-enabling potential of traceability from a whole-of-chain perspective. The following section achieves this in part by comparing the present state of traceability and determining these factors in the seafood industry versus other industries.

Linkage between traceability, practices, and processes

"(T)he ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen and Borit 2013) requires that the information be linked to a physical product and its "transformation" during all stages of production, processing, and distribution. This transformation includes "dis-aggregating" the harvested product into product derivatives (such as fishmeal for animal feeds or fillets for human consumption), or if the product derivatives ultimately become ingredients in processed products (for example, precooked products, ready-to-eat meals, value-added retort-packaged products, animal foods), then throughout the entire life-cycle of the product and that of any of its derivatives or composites. The "life-cycle" of a seafood product is a somewhat ambiguous term, but for our purposes it is defined as the length of time from when a product enters the seafood supply chain—that is, when it is captured in the wild, or at the beginning of a seafood organism's life in aquaculture production—until the time that the product is no longer fit for use by humans for direct consumption or for some other use (such as feed or fertilizer).[2]

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[2]Alternatively, the definition of "life cycle" could be broadened by incorporating the biological life cycle of "wild-caught" products. The size and composition of commercial fishery stocks—and therefore seafood supply—are significantly influenced by resource management decisions (or absence of management)—which in turn reflects concerns about sustainability, one of the global drivers of seafood traceability.

Internal and external traceability. Traceability can be categorized into internal and external traceability. Both are essential for whole-chain traceability (Zhang and Bhatt 2014). Internal traceability refers to the processes that individual firms use which link the identities of the products that enter the firm's operations and the products that leave its operations. Individual firms will also generate and store additional data reflecting changes that occur during the processing and transformational processes, which is added to product identifications. External traceability refers to the ability of firms in a value chain to communicate information about products from some or all stages of transformation to some or all parties in the value chain. Firms generally assign a unique product identifier and adopt some method for communicating this identifier.

The vast majority of firms in the seafood industry already have internal traceability capabilities, both for the purpose of inventory tracking and/or to meet the regulatory requirements of major global markets including the U.S., Japan, and the EU. These internal traceability capabilities manifest themselves in a wide range of ways (Sterling and others 2015). Many of the bigger seafood companies have invested in electronic ERP systems which support many aspects of internal traceability while improving business efficiencies. In contrast, smaller firms may manage traceability-related data in paper form, or in a combination of electronic and paper form.

Very few seafood companies rely solely on electronic systems to record and manage traceability information. A defining characteristic of the global seafood industry is the extraordinary diversity of harvesters, processors, and suppliers—even within the same supply chain. For example, small family-run shrimp farmers in Southeast Asia that maintain data records in paper format may provide the same product to a European supermarket chain that uses complex ERP systems. The relationships that exist between the participating firms will also differ. This fundamental characteristic of the seafood industry—its diversity in size, scale, scope, and relationships—will be a major determinant in developing a global traceability architecture. Addressing this diversity requires a flexible architecture and interoperability that allows firms in the supply chain to exchange and interpret accurate and reliable data while providing data security and controlled access (Global Food Traceability Center 2015; Sterling and others 2015).

Linking traceability to commercial operations

From the perspective of an individual firm in the seafood supply chain, a physical product "enters" a firm's custody, is often transformed in some way during the production, processing, or distribution process, and then "exits" the firm's custody, either to another firm or a consumer. Along with this physical product flow is a series of *processes* that affect the stream of data associated with that product. Every firm in the supply chain conducts these processes that are a fundamental part of the information system—and while our focus is on the seafood industry, they are also applicable to firms in other industries. *Practices* are defined as the strategies and actions that address the requirements of necessary processes. Though these practices are often wide-ranging within an industry, their nature and effectiveness are influenced by the interactions that occur between the value chain in which a firm operates and the wider environment in which the chain operates. Industry-level practices that impact the effectiveness of intra- and inter-firm traceability and the value derivable from these interactions are addressed in subsequent chapters. Of particular importance are content- and context-related factors that must

be considered in designing a technology architecture for enabling global interoperable traceability.

Processes. Key *processes* that affect the data stream associated with any product include:

Product identification: The linking of a physical product throughout a firm's operations, including when product is disaggregated or transformed. Common practices include the use of bar codes, QR codes, physical stamps, labels, and so on.

Data addition: Includes linking additional information on incoming product to information collected throughout the production process. This information may include addition of ingredients, time–temperature history, weight, and portion size, and more.

Data partition: Refers to partitioning all product data into internal and external streams- achieved by determining which data need to be transmitted down the supply chain and which data are kept in an "information silo," or discarded at the firm level. Internal data may be partitioned further into data that need to be accessed readily (for example, in the case of a food safety recall), and archived data.

Data storage: Refers to how data are stored by a firm throughout its production process. Are initial data stored and then additional data linked to them? Are data stored after the product has been shipped? Data storage is an ongoing process throughout a firm's operation.

Data transmission: The mechanisms and processes used to transmit data and information along the supply chain. For example, are data physically attached to the product, or transmitted electronically after the product has been shipped?

Data security and access: Refers to the mechanisms used to ensure the security of data systems at the level of the firm as well as supply chain. Which stakeholders external to the firm have permission to access selected data? How are the permissions effectively managed?

Data collection and measurement: Refers to how data are created and entered into the data system. For example, scales used to weigh products may be connected to a data system electronically, or data may need to be transcribed manually. Barcode readers and QR scanners are commonly used to read a product ID.

Data validation: The process that ensures that checks are in place to produce data that are accurate and valid. This process may include practices ranging from double-checking data by hand, to built-in computer algorithms embedded within ERP systems. At the primary production level, typical validated data may include species, catch area, time, and vessel ID.

These 8 processes and their intra-firm relationships, including physical product flow and data flow, are illustrated in Figure 1.

Assessment of current gaps versus realizable opportunities

Gaps that must be addressed for industry to realize the opportunities that can be gained from establishing global interoperable seafood traceability systems are discussed below.

Regulatory drivers. Regulations are a key forces behind why businesses operating in the seafood industry are embracing traceability. As identified by research, for example, Charlebois and others (2014), Zhang and Bhatt (2014), and Sterling and others (2015) have noted that adopting traceability for strictly compliance reasons can markedly limit the value that businesses derive from implementing traceability systems.

The global regulatory environment influencing the traceability of seafood products is in a state of flux. Many developed countries have recently implemented traceability laws that at a minimum, require a "one-back one-forward" data dissemination and storage
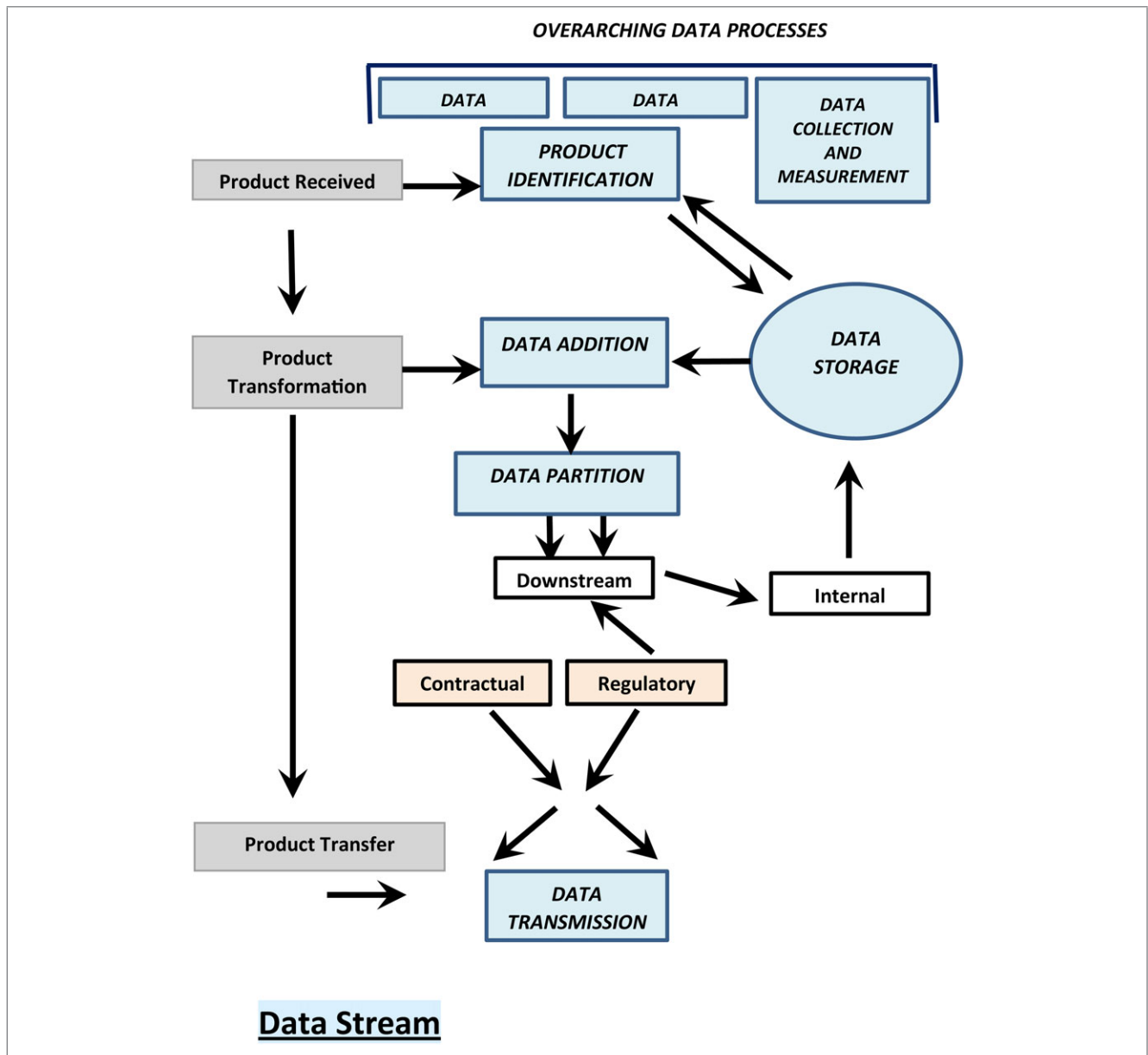
Figure 1–Stylized and generic intra-firm relationship between physical product flow and data flow. The physical product stream is represented by grey boxes and data stream "processes" are represented by italics and blue boxes or ovals.

principle. The one-back one-forward principle requires that each firm in the supply chain keep documentation on all inputs used in the production process (and who supplied it and when) and who received the product (FAO 2014a). Although theoretically this enables whole chain traceability, this system requires that each firm in the supply chain respond to a data request in a timely manner. While many developing countries have yet to introduce traceability laws and implementing regulation, the fact that these countries are increasingly important suppliers of high-value seafood to developed markets means that there is a strong market incentive to comply with the traceability requirements of importing countries (Charlebois and others 2014).

In the U.S. the 2 major pieces of legislation that impact seafood traceability are the Bioterrorism Act of 2002, and the Food Safety Modernization Act (FSMA) of 2011. The Bioterrorism Act gives federal agencies the authority to establish requirements for "im-

mediate prior sources and the immediate subsequent recipients" of seafood (the "one-back one-forward" principle), whereas the FSMA focuses on food safety through the prevention of contamination rather than the subsequent response to it (Future of Fish 2014). The implementation of the FSMA is ongoing; it affirms the Bioterrorism Act and requires that FDA develop traceability requirements for high-risk foods, with traceability pilot projects developed as an integral part of the process (National Fisheries Institute 2011).

All countries in the EU are bound by community legislation. The "European Union Food Law and the Hygiene Package" (FAO 2014b) provides general principles and requirements for traceability based on the one-back one-forward principle pertaining to product identification and labeling requirements, and ensuring/verifying that food safety protocols are followed. The "European Union Rules to Combat Illegal, Unreported, and

Unregulated Fishing" contain a set of regulations that close loopholes that previously allowed seafood from an unverifiable source to be sold in the EU. Among other directives these regulations establish requirements for product validation—that all fishery products sold in the EU are validated as legal by the importing and exporting state (FAO 2014b).

In Japan, the Japan Agricultural Standard (JAS) has labeling requirements that facilitate traceability, although it does not require documentation of the entire supply chain. The Ordinance for the Enforcement of the Food Sanitation Act, which was established in 2007, contains the first requirement for traceability record-keeping; labeling requirements for seafood are not very stringent (FAO 2014b).

In addition to mandatory regulations pertaining to traceability, nonbinding standards and guidelines have been developed by a range of industry and NGO-funded groups including the GS1 organization, the Marine Stewardship Council (MSC), and the International Organization for Standardization (ISO; FAO 2014b). These standards and guidelines pertain to a wide range of value chain aspects including assurance of origin, certification of labor used in production process, and environmental performance of source fishery.

Practices. Specific practices that impact traceability and the values derived from such practices vary widely between companies operating in the seafood industry. Firm size, geographic location, species, industry sector, and position in the value chain (primary producer, distributor, and so on), and the firm's operating principles all impact how the identified processes are conducted. In addition, legal requirements (for example, for record keeping), contractual requirements (for example, a sale is only made if it is accompanied by certain data), and voluntary standards, vary widely between firms, as does the nature of the value chain(s) in which a business operates. The impact of this latter point is discussed in Section 6 and Appendix 1.

The adoption of ERP systems, especially in larger firms, is increasingly important given that ERP integrates many processes together using a single system. For example, data security, partition, addition, and transmission may all rely on maintenance of an ERP system. Figure 2 illustrates a conceptual framework showing the relationship between standards, processes, and practices. Standard- and process-related factors that impact the effectiveness and value derivable from interoperable traceability systems are discussed in Sections 3 to 5, and in Appendix 1.

Value chain determinants. Every business operates within a value chain. Every value chain exhibits characteristics that impact the extent to which businesses can capture value through introducing new practices, processes, and standards and the sharing of related data or information. It is therefore perhaps not surprising that a global study on the impacts and benefits of whole-chain traceability identified a direct correlation between the type of chain in which a business operates and the value that specific businesses can derive from implementing seafood traceability systems (Sterling and others 2015). This was true regardless of the firm's geographic location, its role in the value chain (for example, harvester, processor, distributor, retailer), seafood species, and the firm's size. Value chain characteristics, therefore, are a critical consideration in the design and application of a technology architecture for traceability.

From a value-chain perspective, a common finding is that inefficient and ineffective flow of material through a supply chain is caused by failings in the information flow. This is not just caused by technological deficiency and inefficient practices, but can typically be traced to weaknesses in intra- and inter-firm relationships (see Appendix 1 and Sterling and others [2015] for details). Weaknesses in intra- and inter-firm relationships are caused by a lack of strategic alignment, operational understanding, trust, commitment, benefit sharing, and ultimately collaboration. In terms of the practices and processes associated with traceability systems, these problems result in a reluctance to invest in the necessary assets or skills to develop efficient practices, or an unwillingness to share sensitive information.

In addition, most of the benefits that are realized from implementing a traceability system are not within the control of a single company in the chain. This includes, for example, the integrity of data and information exchanged. Achieving the expected outcomes is therefore dependent upon the behavior of other chain members, and not solely on the sophistication of the traceability-related information practices and technology of an individual firm. The lower the uncertainty over the behavior of others, the greater a firm's confidence will be in its investment in establishing and operating system practices that will deliver the anticipated return. Indeed, the stronger those relationships are across the whole chain, the more ambitious and strategic those investments can be in looking to generate higher and longer-term returns.

Thus, inter-firm relationships will affect firms' expectations as to what returns the information and traceability system should deliver and therefore induce their willingness to invest in more costly and sophisticated "best" practices. A global traceability architecture must address this fundamental reality of supply chains and be able to accommodate the diverse practices of individual firms, as well as the information needs and contractual agreements across entire chains with different levels of trust and strategic alignments.

Enabling Syntactic Interoperable Traceability

As identified previously, the existence of common standards, protocols, specifications, and guidelines (SPSG) is vital to establishing traceability systems that businesses can utilize to capture and create commercial value through implementing traceability systems. This chapter discusses what data are collected and shared that enable businesses to utilize syntactic interoperable traceability. Syntactic interoperability is the ability of 2 or more systems to exchange the same data. Section 4 discusses factors impacting how businesses can create unprecedented value by sharing data in ways that lead to semantic interoperable traceability. Semantic interoperability is the capability of 2 or more systems to meaningfully and accurately interpret the data exchanged. Aspects of "what" and "how" must be considered in designing a technology architecture to enable effective global interoperable traceability.

Factors effecting syntactic traceability

Since the November 2009 release of the FDA-commissioned IFT report "Product Tracing in Food Systems," the IFT-coined terms "critical tracking events" (CTEs) and "key data elements" (KDEs) have gained broad acceptance (McEntire and others 2009). CTEs refer to points within a business and along the value chain where product is moved between premises or is transformed, or is determined to be a point where data capture is necessary to maintain traceability. KDEs are the data required to successfully trace a product and/or its ingredients through all relevant CTEs.

The Bioterrorism Act of 2002 requires that companies that manufacture, process, pack, transport, distribute, receive, hold, or import food must record the source and subsequent recipient. This "one-step forward, one-step back" requirement is CTE/KDE capture in its simplest form. Best traceability practices require that
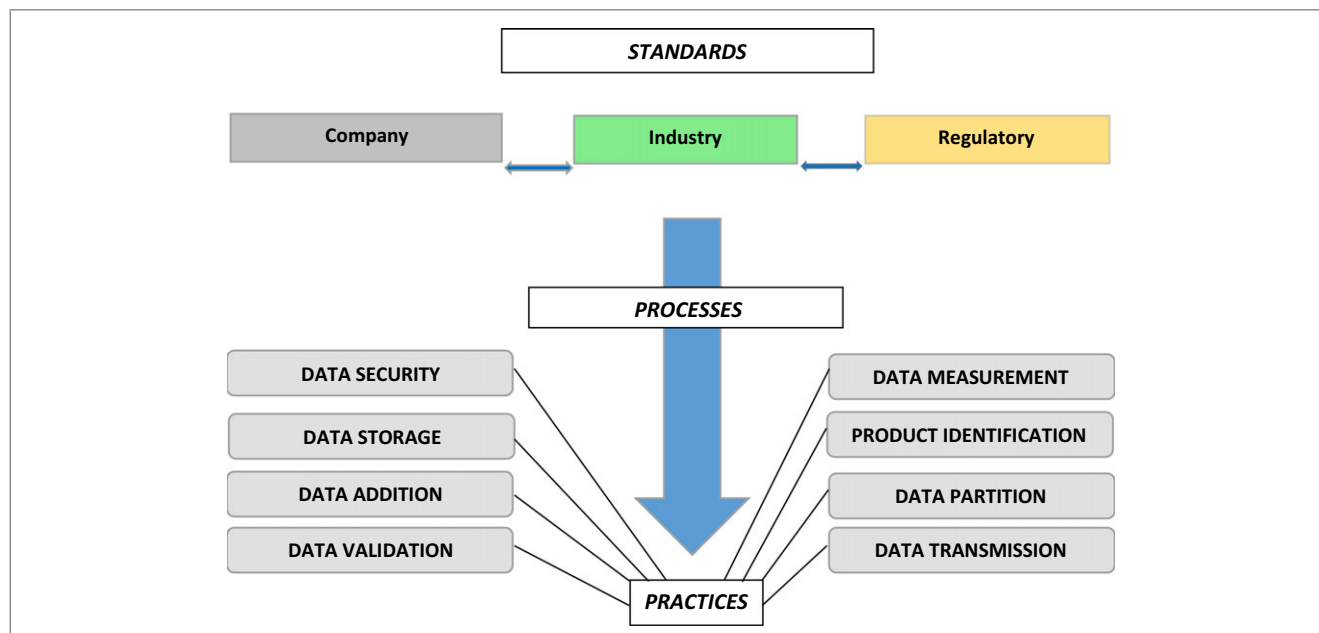
Figure 2–The principles and standards developed by individual firms, industry, and/or regulatory agencies drive the practices that address the required processes.

data (discussed in section "Best Practices") are maintained from all points backward and through all points forward within the chain of custody of a company or trading partner. Generic CTEs may be placed into the categories of harvest, transportation, transformation, and depletion. Effective exchange of KDE information at a CTE is expedited by syntactic interoperability.

The seafood industry, NGOs, and others have conducted research to identify specific CTEs/KDEs that occur along the seafood value chain. These initiatives include: The U.S. Seafood Implementation Guide (NFI 2011), which is intended to aid the adoption of consistent business practices to effectively manage traceability for the seafood industry. The Guide addresses traceability practices from the processing facility to the point of consumer sale to support CTEs such as:

- Product creation/repackaging
- Product shipping
- Product receipt
- Product sale to retailer or foodservice
- Product depletion

The CTEs/KDEs identified in the Guide were agreed upon by seafood traceability experts from different countries and adopted as best practices (Zhang and Bhatt 2014). Research conducted in 2014 on the traceability practices and systems of 48 seafood businesses operating in 9 global seafood value chains identified CTEs/KDEs for 8 fresh and processed seafood products (Sterling and others 2015). In March 2015, a multidisciplinary expert panel published a report that made 8 recommendations for establishing a global framework to ensure the legality and traceability of wild-caught seafood products (EPLAT 2015). The report also provided a table of sample CTEs/KDEs of wild-caught fish products.

At the 2015 SeaWeb Seafood Summit a diverse group of stakeholders participated in a pre-conference workshop entitled "Exploring the Elements of Effective Seafood Traceability, including Key Data Elements." In addition to discussing seafood traceabil-

ity best practices, participants provided feedback regarding NFI's proposed KDEs to identify Seafood Sources (FishWise 2015).

Achieving standardization. Barriers to achieving full traceability for seafood include the lack of standardized systems for data collection and sharing, along with business concerns around confidentiality and data security (Boyle 2012; Future of Fish 2014). Adopting uniform industry requirements for traceability processes ensures agreement about identification of traceable items between parties. This supports transparency and continuity of information across the value chain (NFI 2011) through enabling the effective sharing of accurate verifiable data while maintaining security of sensitive data. Achieving traceability from a whole chain perspective requires appropriate internal processes within the participating businesses and the supporting technology for capturing, receiving, and transmitting information between every step in the supply chain, creating an end-to-end information highway from dock to plate (Future of Fish 2014). As described in Section 2, achieving this relies on the existence of complementary external and internal traceability functions and enablers.

External traceability: All traceable items must be uniquely identified and the information shared among all affected distribution channel participants (NFI 2011). Best Practices for identification of products includes assignment of a unique product identification number or batch/lot number in transportation or depletion events. Batch/lot numbers are required in transformation events (McEntire and Bhatt 2012). To maintain external traceability, this identification must be placed on product labels and related paper or electronic business documents, linking the physical products with the information requirements necessary for traceability.

Internal traceability: Processes must be maintained within an organization to link identities of raw materials to those of the finished goods. When one material is combined with others, processed, reconfigured, or repacked, the new product must have its own Unique Product Identifier. To maintain traceability the linkage must be maintained between this new product and its original material inputs (such as batters, breading, seasonings, marinades,

Table 1–CTEs and KDEs that occur throughout value chain. A, B, and C represent the importance ranking of the CTE.

CTE	A	B	C
CTEs and KDEs that occur throughout value chain			
		Rankings	
CTE type	X		
CTE ID	X		
Event owner	X		
Date and time	X		
Event location	X		
Item ID type	X		
Item ID	X		
Batch/lot/serial number	X		
Quantity	X		
Unit of measure	X		
Batch/lot relevant due date	X		
Activity type	X		
Activity ID	X		
Supplier name	X		
Trading partner location	X		
Temperature		X	X
Specific product attributes		X	X

salt, other ingredients, and packaging materials). A label showing the lot number of the traceable input item should remain on the packaging until that entire traceable item is depleted. This principle applies even when the traceable item is part of a larger packaging hierarchy (such as cases, pallets, or shipping containers).

Water-to-table traceability requires that the processes of internal and external traceability are conducted effectively. Each traceability partner should be able to identify the direct source and direct recipient of traceable items as they pertain to product processes. The implication is not that every supply-chain participant knows all the data related to traceability, but rather shows proof that relevant members/partners in the supply chain have implemented their roles appropriately, that information can be accessed if needed, and individuals or businesses can be held accountable. This requires application of the one-step-forward, one-step-back principle and, further, that distribution channel participants collect, record, store, and share minimum pieces of information for traceability. An example of how CTE/KDE data collection occurs along the seafood value chain is shown in Figure 3.

Best practices reviewed

Following is a review of best practice CTEs/KDEs conducted by members of the Content Mapping TAG, and common gaps in data identified as negatively impacting the effectiveness of interoperable traceability. KDEs are listed along with recommendations on events that occur along the value chain which are critical to track CTEs. They are based on food safety, food quality, food sustainability and food fraud considerations, and reflect current practice in the seafood industry. The most important CTEs are Point of Harvest (farmed and wild), Trans-shipment, Transportation, Processing, and Distribution.

Presented in Tables 1 to 4 are data collected for food safety, sustainability, and species identification. Each table identifies the importance of CTE/KDE data allowing transactional syntactic interoperability regarding value adding. Table 1 lists CTEs/KDEs that are important to identify along an entire value chain. Tables 2 to 4 list CTEs/KDEs for a specific segment of the value chain.

- "A" is a KDE essential for traceability and should be exchanged between trading partners (often referred to as an "external" KDE).

- "B" is a KDE essential for traceability but is collected only for internal purposes and available upon request ("internal" KDE).
- "C" is a KDE that is optional for value-added purposes. They may not be achievable without the presence of semantic interoperability.

Issues and challenges associated with content information

During the review of current best practices, 2 topics that are particularly important for enabling the operation of syntactic interoperable traceability were identified. Each needs to be considered in the technology architecture's design. The topics are: (1) information requirements for enabling syntactic traceability; and (2) challenges to address when designing a technology architecture. Together they provide a brief synopsis of factors to consider in the design of a technology architecture for enabling syntactic full-chain traceability.

Data/information issues for enabling syntactic traceability. Issues for enabling global syntactically interoperable seafood traceability are presented below.

- KDEs related to the harvest and source of wild-caught seafood have not yet been standardized, but are key pieces of information for seafood buyers, customers, NGO partners, and fishery managers. Not all businesses in a supply chain request, share, and maintain the same source information. When they do, they often use different language to capture the same KDE (such as Region of Catch or Location of Catch). There are no uniform guidelines in the seafood industry for how this information is collected and shared throughout the supply chain.
- KDEs and data points for farmed seafood, as for wild-capture, are not standardized and a lack of common terminology creates discrepancies in how information is collected and exchanged between trading partners.
- Port of landing is often a black box in the supply chain where information is lost, not recorded, or, in theory, could be easily falsified. Landing is an important verification point in the supply chain and therefore an essential CTE in which the "who, what, where, when, and how" should be recorded. Not all landing KDEs need or should be communicated to the next level of the supply chain, but can be kept internally by the event owner and made available upon customer request. How such data are collected and stored is important for verification purposes.
- The ability to verify catch/harvest location can be important to enhancing a brand or market name that adds value, (such as Cooper River Sockeye Salmon).
- Identifying/naming the species in trade varies by country. See the Glossary for further notation on Latin/common/market names.
- Fishmeal data are not commonly collected, but they are important for verifying sustainability of feed/potential for labor issues and mitigating business risks. Fishmeal data could be recorded and kept internally by the producer but must be made available upon customer request.
- An IMO Number is obtainable for fishing vessels above 100 GT (IMO 2015).
- Information on the region of catch adds value when an area produces something highly prized, such as ahi tuna.
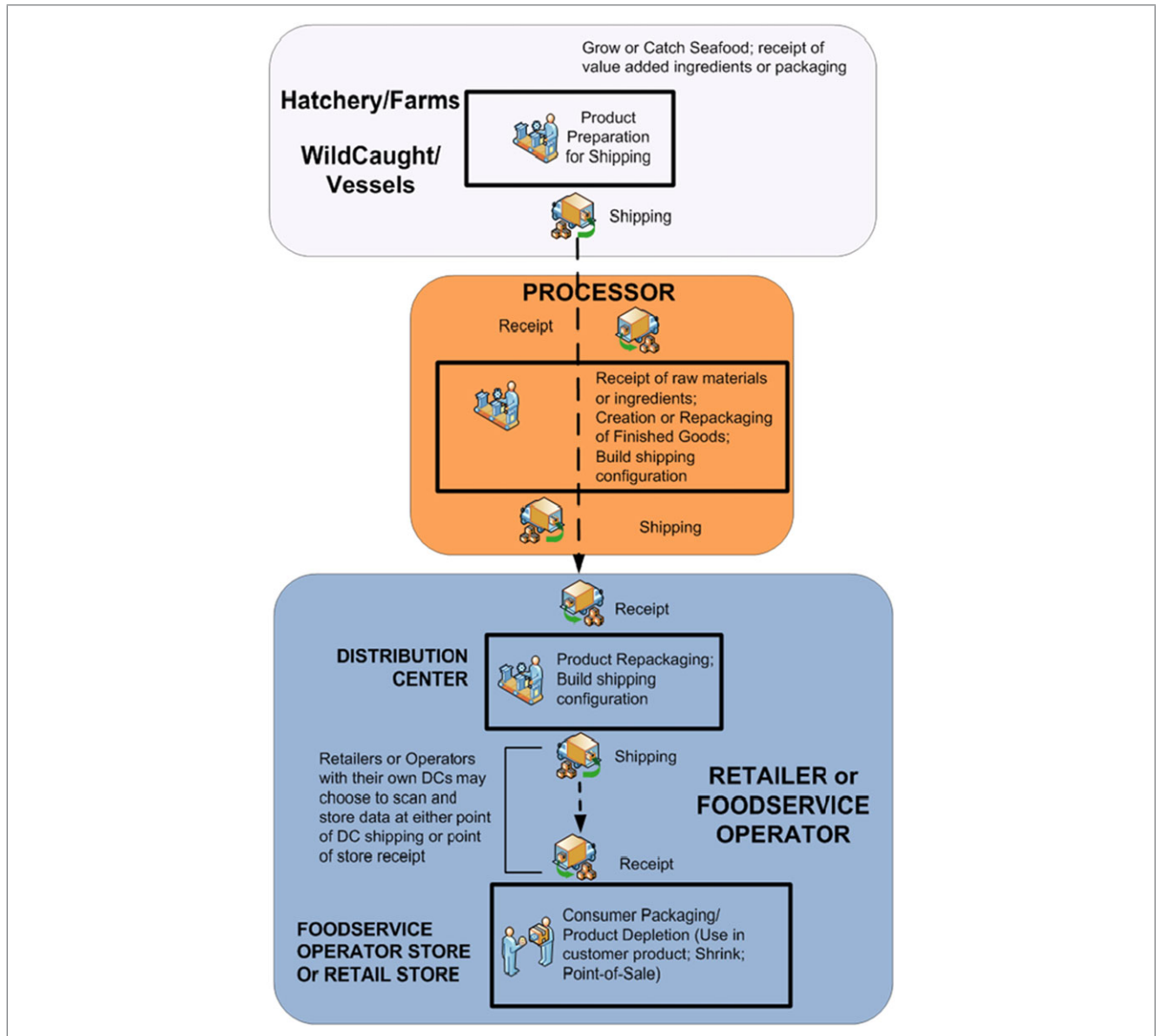
Figure 3–CTE/KDE data collection along the value chain (Zhang and Bhatt 2014).

- Management authority (for example, RFMO) information adds value and applies to a few species, for example, tuna, swordfish, Patagonian toothfish.
- Stock is a fishery management unit but is not a standardized unit of information.
- The FAO has lists of fishing gear and production methods that are widely used by industry.
- Certification status and Chain of Custody Code do not apply to all harvests but may be important to many.
- Catch Date for some species may be a range of dates equaling a trip, instead of one specific date.

Challenges to address when designing a technology architecture. Common challenges that must be addressed to allow the collection of the data and information required to enable effective interoperable syntactic traceability include:

- Species Common Name: Standardized means for identifying fish sold in a country are frequently regulated by that country's government. Thus common and market names for seafood often vary from country to country. In the case of the United States, there is the FDA's The Seafood List which lists Acceptable Market Name(s) and Common Names for seafood products sold in interstate commerce.
- Wild stock: There is no standardized way to identify a fish stock. Identification methods are often a combination of the targeted species, management authority, geographic region, or fishery and fishing gear. These are among the reasons why identifying them and subsequently verifying the location of wild capture and method of capture is so difficult.
- Aquaculture: Standardization is also required for aquaculture production methods, source of fishmeal/oil for feed, farm location, as well as for the harvest dates.
- There is no uniform methodology for data capture/storage/sharing. Also there are differences in terminology used by different stakeholders. These are among the reasons

Table 2–CTE/KDEs for wild harvest.

CTE	KDE		Rankings	
		A	B	C
Point of harvest				
Wild capture				
	Latin species name	X		
	Common or market name	X		X
	Catch location	X	X	X
	FAO major fishing zone	X		
	Country of catch	X		
	Region	X		
	Management authority	X		
	Stock	X		
	Landing date		X	X
	Time of harvest			
	Vessel info			
	Flag of fishing vessel		X	
	Name of fishing vessel	X	X	X
	Captain name		X	
	Home port		X	X
	IMO	X	X	
	Fishing method	X		X
	Total weight of catch		X	
	Certification status and chain of custody code		X	X

Table 3–CTE/KDEs for farm raised.

CTE	KDE		Rankings	
		A	B	C
Point of harvest				
Farm				
	Farmed location			
	Farm name or processor name	X	X	
	Country of farming	X		
	Region of farming (or address)	X	X	X
	GPS coordinates		X	X
	Country of origin labeling (COOL)	X		
	Production method	X		
	Fishmeal KDEs			X
	Feed company name		X	
	Feed ingredients		X	X
	Hatchery name		X	
	Source information for wild fish feed	X		
	Catch area	X		
	Flag of fishing vessel		X	
	Name of fishing vessel		X	
	Fishing gear	X		

why that which may appear as simple data, such as those associated with catch or harvest date, can be difficult to verify.

- FDA remains quiet on its traceability requirements for food safety, though the FSMA mandates that the agency promulgate traceability requirements on high-risk foods. IFT's recommendation to FDA was that all foods be subject to trace requirements. NOAA is more vocal, and at this writing, the agency is commissioned to propose a seafood traceability system for species at risk for sustainability issues and fraud with the intent to expand the list to all species at first point of sale or import. The question of which KDEs must be shared with the agencies for enforcement purposes and which KDEs should be shared between supply chain companies is an important one for the industry as proprietary information is at stake. Of course, when a recall investigation is ongoing, the agencies are entitled to all information relevant to the trace-back.
- NOAA has proposed the International Trade Data System (ITDS, which is expected to be online December 2016) as the platform for some or all data collection concerning sustainability and fraud. NOAA touts ITDS as an interoperable system. ITDS is a data entry platform for review of industry import/export data by the federal agencies, including Customs and Border Protection. Although a one-way portal is interoperable in that it is a single window for multiple agencies (meaning data need only be entered once), whether ITDS is readily modified for a plethora of KDE data on sustainability and species verification remains to be seen. ITDS will not serve as an interoperable system for data exchange among business partners or as a means for conveying information to consumers (NOAA 2015).

Enabling Semantic Interoperable Traceability

Without a common language to which internal and external systems adhere, semantic traceability cannot occur. Achieving semantically interoperable traceability relies on establishing a common set of terminology and hierarchy, sometimes referred to as a common information model or ontology.

An example of the extent to which the required ontology presently does not occur is evident in the differences in definitions of seafood species across countries. For example, Canada and the U.S. are important trading partners. The Canadian Food Inspection Agency (CFIA) lists nearly 800 species of seafood; the

Table 4–KDEs for CTEs of retained bycatch, trans-shipment, shipping and receiving, transportation, port/landing, processing stages, primary/secondary, and distribution.

CTE	KDE	Rankings		
		A	B	C
Retained bycatch				
	Species	X		
	Stock			X
	Size of Bycatch		X	
	Quantity of Bycatch		X	
	Date and Time of Bycatch		X	X
	Location of Bycatch	X		
	Catch Certificate/License	X		
Trans-shipment				
Shipping and receiving				
	Was the Product Trans-shipped?	X		
	Tonnage Trans-shipment		X	X
	IMO Number of Catch Vessel and Carrier		X	X
	Identity of Receiving and Shipping Vessels	X	X	
	Date and Time of Transfer	X	X	
	Location of Transfer	X	X	
	Species or Common Name	X	X	
	Quantity	X	X	
	Lot, Batch of Shipment Number	X	X	
Transportation				
Port/landing				
	Location Landed	X	X	
	Date Landed		X	
	Identity of Vessel	X		
	Event Owner	X	X	
	Species, Stock, Size	X		
	Catch Certificate of License Number		X	
	Quantity of Fish		X	
Processing stages				
Primary and secondary				
	Species	X		
	Dates and times received	X	X	X
	Location received	X	X	
	Weight	X		
	Lot number	X		
	Batch code	X		
	Dates and times shipped	X	X	
	Name of processor/packing plant	X		
	Pallet identifier	X		
	Supplier		X	
	Customer		X	
Distribution				
	Product	X		
	Weight	X	X	
	Container/seal number	X	X	
	Pallet identifier	X	X	
	Lot number/batch number/serial number	X		
	Pallet identifier	X	X	
	Dispatch date	X	X	
	Receiving date	X	X	
	Transport companies	X	X	
	GTIN code/UPC code	X		
	Quantities	X		

U.S. Food and Drug Administration (U.S. FDA) lists more than 1,800 species. The similarity between the CFIA and U.S. FDA lists is approximately only 500 species. Such misalignment in the terminology surrounding species leads to compliance challenges and limits traceability effectiveness. Expand this to differences in species listed by countries worldwide, along with wider implications such as the terminology used to identify catch location, and the need to establish a common ontology quickly becomes evident.

A seafood traceability ontology is needed to facilitate and simplify interoperability among technology providers, businesses, and other stakeholders. Sharing of foundational standards and terminology allows the market to be open to workable interoperable solutions. Without adhering to a clear and concise ontology, issues arise that undermine the effectiveness and value of traceability, particularly in instances where traceability relies on the sharing of data across multiple networks and technologies.

The following chapter identifies the protocols, practices, specifications, standards, guidelines, and uniform requirements needed to achieve semantic interoperability. To aid the creation of an ontological hierarchy that formalizes terms and relationships, the Context Mapping TAG began by conducting a literature review and environmental scan of existing ontologies, protocols, practices, and standards in the seafood industry. The TAG then conducted a gap analysis to identify factors impacting the effectiveness of traceability systems and practices. This involved mapping existing and desired ontologies, protocols, practices, and standards in the seafood industry that could be useful in designing a technology architecture for enabling semantically interoperable seafood traceability.

Factors effecting semantic interoperable traceability

Lack of standardized data language requirements and proprietary data protection are among the challenges that negatively impact data sharing in the food sector as a whole. Currently, standards are applied (often voluntarily) by individual businesses. Standard-setting organizations may differ in the standards that they communicate to businesses and sectors according to their geographic location.

Seafood terminology standards. Existing standards that are applicable to traceability and interoperability include GS1 product identifiers, such as the Global Trade Item Number (GTIN) and serial numbers or lot numbers along with GS1 data carriers, including familiar linear barcodes. The GS1 Global Data Synchronization Network (GDSN) provides for unambiguous description of the products. DataMatrix and EPC-enabled RFID can create the ability to reference products throughout a value chain. The Foundation for Fish, Seafood and Aquaculture Traceability Implementation Guideline (GS1 2015) provides guidance on implementing GS1 standards following the theme of "Identify–Capture–Share–Use." The document provides specific guidance about assignment of GTINs given certain unique aspects of seafood supply chain product characteristics based on descriptions of supply chain processes and roles.

The greatest value of standardized data lies in the ability of trading partners to establish a transparent supply chain. The ability to "see" what is happening from dock to plate enables effective proactive management (Sterling and others 2015). Traceability is a visibility-enabling application that leverages event-based information about products to support track and trace, and recall. GS1 Standards are open and scalable allowing global industry interoperability. In addition to standards, GS1 has developed a GS1 Systems Architecture to address the interoperability between the standards, interrelated hardware and software, and the supply chain processes and roles. GS1 (2014) indicates that the standards "define interfaces between system components that facilitate interoperability from components produced by different vendors (or in house)," and that the GS1 System Architecture is an open, vendor-neutral, platform-independent system. See reference GS1 2014 for a more detailed review of the GS1 System Architecture.

The Marine Stewardship Council (MSC) has a Chain of Custody Standard (MSC 2015a) that addresses seafood traceability; the standard is applicable to the full supply chain from certified fisher or farm to final sale. The standard "ensures that only seafood from wild-capture fisheries certified to the MSC Fisheries Standard for environmentally sustainable fishing can carry the MSC ecolabel and claim," and it is also used to "ensure the integrity of the supply chain for responsibly farmed seafood certified to the Aquaculture Stewardship Council's (ASC) standard" (MSC 2015b). The MSC Chain of Custody Standard requires each company in the supply chain that handles or sells an MSC-certified product to have a valid MSC Chain of Custody certificate and that certified product must be traceable through to the point of sale (MSC 2015a). The MSC Chain of Custody Standard has 5 principles:

1. certified products are purchased from certified suppliers,
2. certified products are identifiable,
3. certified products are segregated,
4. certified products are traceable and volumes are recorded, and
5. the organization has a management system.

Principle 4 requires traceability records to be able to link certified products at every stage between purchase and sale, including receipt, processing, transport, packing, storage, and dispatch. Other chain of custody certificates include Fair Trade, and the Global Aquaculture Alliance's Best Aquaculture Practices (Boyle 2012).

Can-Trace has a Canadian Food Traceability Data Standard (Can-Trace 2006a) for whole-chain traceability of food products. The voluntary standard is based on international standards (GS1 and ISO) and the European Article Numbering-Uniform Code Council (EAN.UCC System). Can-Trace addresses the minimum (mandatory) 12 and optional 11 information requirements that should be collected, kept, and shared between trading partners for whole-chain traceability. With respect to seafood, the standard identifies data requirements for primary producers, processors, wholesalers and distributors, and retail/store/foodservice operators. To support this standard, Can-Trace provides Technology Guidelines (Can-Trace 2006b) about enabling technologies for product markings (for example, bar codes, RFID) and document exchange (Electronic Data Interchange [EDI] and Extensible Markup Language [XML] standards).

Two ISO standards address traceability: 12877:2011 is for information to be recorded in farmed finfish distribution chains and 12875:2011 is for information to be recorded in captured finfish distribution chains (ISO 2011a, b).

Ontologies, architecture technology solutions, and interoperability

Defining ontology. Gruber (1993) provides a core definition for the concept of ontology: "an explicit specification of a conceptualization." Noy and McGuinness (2001) stated that an ontology is a common vocabulary for researchers who need to share information in a domain and that it includes machine-interpretable definitions of basic concepts in the domain and relations among them. More specifically, they said, an ontology is a formal explicit description of concepts in a domain of discourse (classes/concepts), descriptive concept properties (slots/roles/properties), and restrictions on slots (facets/role restrictions), and that an ontology with a set of instances constitutes a knowledge base. Zelewski and others (2012) described ontologies beyond the conceptualization perspective from one of linguistics. They explained that ontologies are used for work-sharing tasks and only need to involve possible real-world experiences of the agents that are of interest for between-agent communication regarding coordination of activities. Pizzuti and Mirabelli (2013), who developed an ontology for food system traceability, said that the main purpose of an ontology is to "enable communication between computer systems in a way that is independent of the individual system technologies, information architectures and application domain."

Advances in system interoperability that enable traceability

Advances in automation, open standards, and information management, such as through the "Internet of Things," are aiding traceability and offer great potential in designing a technology architecture suited to enabling global semantic interoperable traceability for seafood. Applications of GS1 standards and technologies for traceability architecture, based on a defined industry process flow along with supply chain roles, have been created by several solution providers. In addition to unique product identification, and the encoded identification in GS1 Data Carriers, the interface standard named Electronic Product Code Information Services (EPCIS) along with the Core Business Vocabulary enables the

physical event of data capture and query of the "who, what, where, when, and how" of the product's life-cycle in a supply chain. The following summary describes examples of solutions designed to enable interoperable traceability across sectors, not just seafood or food *per se*.

Interoperability research and enablers. Most interoperability efforts have occurred in other sectors of the food industry or entirely different industries, not seafood. Bhatt and others (2013a) and the "Implementation of the FDA Food Safety Modernization Act Provision Requiring FDA To Establish Pilot Projects and Submit a Report to Congress for the Improvement of Tracking and Tracing of Food" (FDA 2013) described how service providers tested different approaches for using technology platforms to perform the convergence queries required to enable semantic traceability. Some solutions were only able to follow one leg of a supply chain at a time, resulting in following the flow of products back to the source (farm or ingredient supplier) one query at a time. Some had an incrementally better approach where the queries would be a series of tracebacks and traceforwards in order to find convergence: for example a traceback of a product to its source, and then a series of traceforwards of that source to find common retail outlets.

Food industry initiatives. A technology provider had built-in capability to input a series of retail locations and run the query to find common lots of convergence that could have been shipped to those retail outlets (this included querying the immediate supplier of products, such as a distribution center, as well as the source supplier of products, such as ingredient suppliers or growers). A few others built new queries based upon the requirements of the pilots to demonstrate that convergence can be found, as well as highlight the fact that their technology platform can be customized to the needs of the end user (in this case, the FDA). The result of these practices was that interoperability was achieved when work was based on the ontology of supply chain process definition and supply chain roles.

FoodLogiQ Connect, a cloud-based platform for connecting the food industry enables end-to-end traceability, compliance validation, and sustainability benchmarking with a cloud-based traceability program leveraging GS1 Standards (GTIN, GLN, EPCIS, Core Business Vocabulary) for tracking and sharing standardized product information at every step along the supply chain (Foodlogiq 2015). The FoodLogiQ implementations are based on industry supply chain process definitions offering interoperability with other solutions using GS1 Standards as the foundation.

Brizzi (2014) and Furdik and others (2014) described the development of a prototype platform architecture that was a pilot application of the FP7 EU project ebbits demonstrated with beef. The platform architecture was built on the Internet of Things (IoT), People, and Services, and the prototype involved adaptation of LinkSmart middleware as an IoT enabler, a semantic model, and a Thing management module, which comprises the traceability architecture node and includes a Product Service Orchestration component. In an overview of the ebbits project, Brizzi (2014) indicated that it supports multiple domains (for example, automotive and food traceability) and allows interoperable end-to-end business applications across stakeholder boundaries.

Folinas and others (2006) introduced a generic traceability data management framework (architecture) for fresh, nonprocessed food product supply chains based on the XML (eXtensible Markup Language) Schemas technology, a W3Consortium standard. W3C is an international community in which member organizations, staff, and the public develop web standards (W3C 2015). Phys-

ical Markup Language (PML), an XML standard technology, is proposed as the common language for describing physical objects/products flowing along the chain. The data management framework has 4 phases: identification and classification, transformation and modeling, processing, and presentation of traceability data. Common business vocabularies that describe the structure and the semantics of the traceability data allow users to document requirements in a neutral format that act as a standard. The main features of the system, they noted, are: adequate filtering of information, information extracting from databases that already exist for supporting food quality and safety standards (HACCP, ISO, GAP, GMP); harmonization with international codification standards such as GS1 standards; and harmonization with internet standards and up-to-date technologies. They said the system is simple and user-friendly because it allows information to flow through conventional technologies.

Magliulo and others (2014) described the development of ontologies and taxonomy for traceability in the dairy industry, illustrated with the Bovlac Platform—a project that extended traceability to quality data for the cheese product "Fior di latte Napoli." The project involved the ValueGo® ICT web-centric platform developed for traceability, and allows consumers to scan with a smartphone the QR-Code on the product package to read the product history. ValueGo® technology has domain ontologies and is based on RFID or NFC radiofrequency and bar code identification technologies, with a semantic database implementing the application domain ontology. ValueGo® builds on ValueGo® Java Framework and includes classes to manage an EPCIS Repository. The system transmits data during production phases in real time to a portal. The system is adaptable to different product processes and supply chain models (Magliulo and others 2014).

In a blog of the ITU (the United Nations' specialized agency for information and communications technologies), Jian (2014) reported that China's administration has implemented the National Food Quality Safety Traceability Platform in collaboration with food manufacturing and ICT industries. It was noted that the platform, implemented first by the dairy industry and with connections among large infant formula manufacturers, draws on technological developments such as the IoT, and uses, for its core technical framework, the Handle System of Digital Object Architecture, developed by the Corporation for National Research Initiatives (2015).

Nonfood-related. Musa and others (2014) conducted an extensive review of recent developments in architectures, technologies, and software for product visibility at the item and aggregate levels. They described in detail 4 of the existing architectures and structures for supply chain visibility currently in use. Their review included a survey of user needs for traceability systems and structures among 200 respondents across industries and business sectors in the United Kingdom. The authors commented that user needs and assessment criteria for visibility systems are industry-dependent, and that users want a relatively simple system that meets their needs. They noted that ontology-based approaches for semantic standards could be a solution to seamless interoperability of disparate systems. They mentioned several types of ontologies—source, user, application, and shared—for modeling data sources and said it is expected that ontologies will become used more frequently for supply chain intelligence in the future.

For the health care field, Sittig and Wright (2015) proposed a working definition for open or interoperable electronic health records. They proposed 5 "use cases," which they referred to as the Extract, Transmit, Exchange, Move,

Embed—EXTREME—capabilities, and they recommended that health care delivery organizations should require these. Each use case, they said, represents important functionality to clinicians, researchers, administrators, software developers, and patients. They described in detail the requirements for each of the 5 use cases.

Food Track and Trace Ontology (FTTO) prototype

Pizzuti and Mirabelli (2013) and Pizzuti and others (2014) described the development of a Food Track & Trace Ontology (FTTO) prototype for the food traceability domain that can be used to share knowledge between agents along the food supply chain. They said many graphical notations, including the popular entity–relationship diagrams (ERDs), are used by different people with a different meaning in mind. This hampers data/information exchange and the reuse of models. A common ontology would unify the metadata model to express knowledge resources that are diverse in type and disunited in form. The FTTO is a single ordered hierarchy/taxonomy, using the software Protégé, which automatically generates ontology code in Ontology Web Language and classifies food in a taxonomy of terms. The FTTO enables interoperability among different systems and integration of the heterogeneous databases adopted by each actor of the food supply chain (Pizzuti and others 2014). The FTTO uses OWL-DL language based on description logics to describe the food traceability domain; and queries are formulated in Description language (DL-QUERY). Pellet plug-in is used as reasoner. The ontology is designed to connect with global traceability information systems.

The FTTO consists of 2 main classes: food product and process (Pizzuti and Mirabelli 2013). The food product class includes food in the form of primary food commodities or processed products, beverages, and food additives used during the phases of production. The Process class includes business processes and agro-food processes operated by the different agents involved in the food supply chain. The taxonomy used to define the Food Product class was based on the Codex Classification of Foods and Animal Feeds (CAC 1993), and the food hierarchy considered several other taxonomies. There are 2 main subclasses, which are Primary Food Commodity and Processed Food. The Processed food category is differentiated into Derived, Secondary, and Manufactured. A series of data properties was associated with each food product, such as name, variety, and category. In addition, for each food product the annotation product *hasCode* was introduced. The code used to codify products is fundamental for the generation of a bar code or QR Code to correlate with each food product. Pizzuti and others (2014) described 4 separate modules for key concepts in the traceability domain: Agent (actors, such as primary producer, processor), Food, Process, and Service product.

More recently, Pizzuti and Mirabelli (2015) described in detail the methodological approach they used in designing and developing a framework for a traceability system—Global Track and Trace Informative System (GTTIS)—that is adaptable to different types of food industries. They said the development requires modeling of business processes and associated data results; the framework they proposed was modeled according to the BPMN (Business Process Model and Notation) standard. They used a 5-step approach to develop the GTTIS: (1) food supply chain analysis; (2) food supply chain modeling; (3) data collection; (4) data modeling; and (5) generation and customization of the web-based application for traceability management. The relational database was generated in the 4th step. They mentioned examples of the different techniques and software that can be used to model the sequence of processes executed by different supply chain actors and the re-lationships between actors and processes, develop the traceability database model at the base of the system, develop and implement the general data model, define the encoding rules, and integrate the process models and data models.

Seafood industry activities and developments

The following section describes developments in interoperable traceability in the seafood industry, along with industries that have established advanced systems. The purpose of including other industries is to illustrate insights and lessons learned that can guide the development of a technology architecture suited to enable semantic interoperability across the global seafood industry.

Seafood interoperability initiatives. Ringsberg (2011) evaluated fresh fish supply chains via case studies in Scandinavian countries, finding that there are 3 categories most valuable for classifying beneficial traceability information in fresh food supply chains by product, transportation, and items. Ringsberg found structural differences between information systems in the Nordic countries, with Sweden and Norway having decentralized information systems (several databases at each actor that contain traceability information), and Denmark having a centralized information system (one central dataset for storing traceability information). Among the details provided about the information systems used for traceability, they noted that the Norwegian fresh food supply chain was based on the voluntary information standard, EPCIS, and that both the Danish and Norwegian supply chains used EPC Gen 2 for standards information transfer and secure web-access (XML) and ERP solutions for connection to the information systems. Ringsberg (2011) used 2 processing modeling techniques to analyze the data about physical and information flows: processing mapping and cause-and-effect diagrams. He found that the cause-and-effect diagram technique was most appropriate when analyzing time differences while the process mapping diagram technique was most appropriate for analyzing the physical material flow due to temperature demands in fresh supply chains. Ringsberg indicated that a combination of the 2 should be used. Further, Ringsberg (2011) found that, at the time of the study, no international standard was used for labeling items through the 3 supply chains in the fish industries, and he suggested that they be developed.

Gunnlaugsson and others (2011) described application of the EPCIS standard, originating from EPCGlobal, RFID, and Unified Modeling Language (UML) for food traceability in a pilot test with one-day redfish catch for a ground-fish processing plant in Iceland through to packaged items for distribution. The "eTrace project" had the goal of specifying, developing, and evaluating an electronic traceability system that integrates different information sources relating to food safety and enterprise management systems. The project had 13 "states" (logistics and stock management processes, use of production equipment, and important transformation processes) and 26 generic transitions that could provide traceability information in data collection at specific points in the production process. The EPC Scheme included 9 GS1 Identification Keys, including Global Location Number (GLN), Global Returnable Asset Identifier (GRAI), and Serialized Global Trade Item Number (SGTIN). An EPCIS repository, by TraceTracker (Oslo, Norway) stored and managed standardized "event" data (the "what, why, when and where") of individual items, and allowed sharing of information. The authors indicated that the system provides the opportunity for sharing with other stakeholders in the value chain actor-controlled, internal, standardized traceability information.

Commercial initiatives. In 2013, METRO Group (Duesseldorf, Germany) piloted a German project for fish products—called

"Traceability in the Cloud"—centered on recording data electronically, with decentralization via an integrated software platform, and based on open international standards (GS1 AISBL 2014). The system has a search engine allowing retrieval of details about individual batches and also makes data available to consumers via barcodes on packaging or information on invoices via the fTRACE internet platform or smartphone application. METRO uses GS1's open standards in their supply chain for traceability in business-to-business (B2B) commerce (GS1 AISBL 2014). METRO SYSTEMS designed the company's traceability solution, which is built on a real-time event repository used in its RFID program and based on open global standards such as GS1's visibility-enabling standard EPCIS and is scalable and extendable to nonfood sectors (GS1 AISBL 2014). More specifically, "As fish products travel through the supply chain from fishermen to processors to distribution centers and on to METRO AG Cash & Carry locations, the identification data are scanned at various points along the way. The GS1 EPCIS and Core Business Vocabulary (CBV) standards together provide the foundation for all trading partners to share real-time information about the movement, history and status of the fish products as they travel through the B2B2C supply chain" (GS1 AISBL 2014). Britta Gallus, Director of Group Regulatory Affairs, Traceability Project Lead, METRO GROUP, stated that "We needed a platform that could interoperate with our different suppliers' systems" (GS1 AISBL 2014). As indicated and elaborated on by GS1 AISBL (2014), "GS1 Germany recommended fTRACE, an open platform based on GS1 standards that could easily scale for METRO Cash & Carry's vast array of products and meet METRO's expectations; fTRACE also offered decentralized data management for ease of integrating diverse databases and interfaces."

Parreño-Marchante and others (2014) studied the value for 2 aquaculture companies, in Spain and Slovenia, of moving from a paper-based traceability system to one that is based on electronic technologies. They developed and tested an interoperable architecture that is based on the standardized EPCglobal Architecture Framework. The system, which they proposed to help small to medium enterprises in the aquaculture sector, uses web services to integrate traceability data generated in the form of events, captured in RFID systems, with information about the environment collected with a Wireless Sensor Networks infrastructure. The system has 4 main components: (1) RFID Readers, Sensors, and Data Input devices; (2) set of capture and query applications; (3) traceability repository; and (4) set of web services. The architecture allows sharing of some of the collected information (for example, aspects relating to product origin, quality, and handling) at retail with the customer. Items carry an ID that is stored as a URL and conveyed by a QR Code to a smartphone, identifying the smallest logistic/traceability unit in a machine-readable format and including times and dates, names of processing steps and states, and locations and pointers to sensor data (temperatures) retrieved from the traceability events. The authors stated that the information is combined with generic textual information about the product (for example, fish type, size, and description), nutritional information, and expiration dates, for presentation in a web page with images, graphs, maps, diagrams, and descriptions. They noted in their field tests some deployment challenges arising due to the offshore work environment and harsh environment and structure of the processing plant that they considered. They reported that the interoperable system is flexible, scalable, and adaptable to other food sectors.

Summary of findings

The research on semantic interoperability illustrates why the development of a common ontology is critical to the development of interoperable technology systems. Establishing a common ontology is particularly important for enabling the implementation of effective whole chain traceability in such a diverse and complex industry as seafood. Findings from the review also show that an ontology cannot be developed in isolation. It must take into account the technologies that enable traceability systems to operate and how these technologies are utilized by commercial businesses. In the words of Pouchard and others (2000), "ontology engineering aims at making explicit the knowledge contained within software applications, and within enterprises and business procedures for a particular domain." Additionally, they stated, "Ontology engineering offers a direction towards solving the inter-operability problems brought about by semantic obstacles, i.e. the obstacles related to the definitions of business terms and software classes. Ontology engineering is a set of tasks related to the development of ontologies for a particular domain." Establishing a common ontology requires extensive stakeholder input. This is a challenging process, especially where stakeholder familiarity with the nature of ontologies and the importance of their role in interoperable traceability is limited.

Learning from Other Industries

To assist the design of a common technology architecture that enables businesses to create and then capture value from having effective syntactic and semantic interoperable global seafood traceability, a number of other industries were examined to identify lessons learned that may assist in the development of relevant SPSGs. How SPSGs were developed and governed to ensure the continuation of effective interoperable traceability by evolving with industry requirements was also examined. Though the drivers of traceability or the structure of these industries may differ from the global seafood industry, the advanced traceability practices of these industries provide valuable insights. Further detail is in Appendix 1.

Automotive

The global automotive industry is dominated by large corporations based in the U.S., China, Japan, South Korea, and Europe. Automobile manufacturers have significant power and authority over the rest of the supply chain, making stringent quality demands and requiring information sharing as a prerequisite to conducting business. The current trend in the automotive industry is towards outsourcing production of individual components to firms located all over the world. The contracts awarded to component manufacturers and business relationships that occur along the value chain differ markedly.

The large number of components that make up a vehicle has resulted in extremely complex and dynamic supply chains, and distribution of information on components and sub-components involving a large number of firms (LNS Research 2012). A single vehicle is generally made up of thousands of components often sourced from hundreds of different companies around the world (AMS 2014). Apart from fighting increasingly rampant counterfeiting of replacement parts (worth almost $12 billion in 2013 (AMS 2014)), adhering to strict recycling regulations in countries such as Japan (Murthy and others 2008), and improving business efficiencies (IBS 2012), the main driver of traceability corresponds to adhering to mandatory safety recalls of defective parts (Cognex

2011). Secondary drivers include broader concerns about safety issues, fraud, efficiency, and waste.

The current focus of traceability in the automotive industry centers on tracing each automobile component to its source, and throughout the entire life cycle of the vehicle (Cognex 2011). Firms in the industry generally maintain sophisticated ERP systems, and they use these systems to link sub-components to components, sub-assemblies, assemblies, and finally to the completed automobile. Enterprise Quality Management Software (EQMS) packages are increasingly being used to facilitate the integration of a firm's ERP with its business processes (IBS 2012). This type of software facilitates quality management across a firm's complex operations and allows disjointed modules of an overall ERP system to communicate effectively (LNS Research 2012).

The physical component of an advanced traceability system in the automotive industry increasingly takes the form of Direct Part Marking (DPM). Every component of an automobile is given a unique identification that is affixed to the part in a range of ways. These methods differ depending on the material, requirements for readability, and requirements for durability. For example, ink jet printers may print codes on plastic parts, while metallic parts are laser-etched with codes. Codes are generally machine readable, and while 1D barcodes are commonly used there is an increase in the use of 2D codes which have the advantage of being able to store a significant amount of data, and are readable even when damaged (Freedom Corp 2007). To avoid production errors, many manufacturers produce build sheets for a sub-assembly containing the required component identifications. Operators then scan each part in the assembly process to ensure that the correct part is being used.

Industry-wide interoperability. The Automotive Industry Action Group (AIAG) has played a central role in establishing interoperable traceability across the global automotive industry. AIAG is a not-for-profit association of diverse stakeholders, including retailers, suppliers of all sizes, automakers, manufacturers, service providers, academia, and government, who collaborate to streamline industry processes via global standards development and harmonized business practices. Through engagement with automotive and component manufacturers, AIAG developed and manages AIAG Supply Safe™, a suite of tools designed to ease challenges associated with transparency and compliance reporting in the global automotive supply chain. The Supply Safe portal is a gateway for the industry first C-TPAT (Customs Trade Partnership Against Terrorism) Supplier Security Assessment for tracking origination and flow of raw materials, parts, and finished goods through the supply chain (AIAG 2015). The portal allows suppliers to create free security and reporting profiles through the Supplier Security Assessment link on the Supplysafe.org homepage.

Other AIAG features and initiatives for members include AIAG Supply Power-related free access to industry EDI/Packaging standards as part of Global Materials Management, and free AIAG-developed Data Standards and Global Communication Requirement profiles as part of Global Connectivity. A Global Materials Management Operational Guidelines/Logistical Evaluation (MMOG/LE) tool for improving materials management, with certification capability, can be used by suppliers and customers throughout the entire life cycle of a product. MMOG/LE is the "global standards supply chain management processes that provides industry best practices" and is "intended to establish a common definition of materials practices to facilitate effective communication between trading partners" (AIAG 2015).

Specific achievements cited by AIAG (AIAG 2015) that have enabled interoperability to occur across the automotive and component manufacturing industry include:

Bar code standards: development in 1984 of a single alphanumeric bar code symbology and standard for the industry, and pioneering of the concept of data identifiers (alphanumeric strings indicating part number, purchase order number, quantity, and so on), which was benchmarked by the aerospace and other industries and the U.S. Dept. of Defense.

Electronic data interchange (EDI): standardization: adoption of the American National Standards Institute's ASC X12 protocol with its variable-length format; global harmonization of the standard; and publication of the industry's first EDI Implementation Guideline.

Trade collaboration system: development of a computing-based cloud allowing authorized tracking of shipments and document access, and complete interoperability and supply chain operation visibility.

Data specification: development of a simple, flexible, and generic non-proprietary standard—QMD specification—that allows variable, attribute, and binary quality measurement data from any source in any format to be seamlessly translated; eliminating the need for multiple systems and data integrators.

Within the World Wide Web Consortium (W3C), the automotive industry is working to provide drivers and passengers in "connected cars" with web-based data and services. In 2013, the Automotive and Web Platform Business Group was formed to ensure that the Open Web Platform, an interoperable system, will meet industry needs and help stakeholders understand W3C standardization processes (W3C 2013). In 2015, W3C launched the Automotive Working Group to develop Open Web Platform specifications for HTML5/JavaScript application developers enabling Web connectivity through in-vehicle systems and protocols (W3C 2013).

Fresh produce

The fresh fruit and vegetable industry is increasingly globalized, supplies a growing wide range of products, and generates approximately $2 trillion in revenue annually (First Research 2015). Large multinational and geographically diverse organizations operate in the produce industry. However, differences in the scale and the types of suppliers, including distributers, wholesalers, shippers, and importers, that serve food service operators and retailers, make it difficult to make generalizations about the industry. In addition, the limited power and authority of individual organizations over the wider industry make the produce industry more comparable to seafood than automotive in terms of industry structure. What is comparable to both automotive and seafood is that firm characteristics tend to vary by the product or product group that each business supplies (Cook 2011).

Three major current trends are impacting the produce industry. The first 2 are driven primarily by changes in market dynamics: (1) growth of sales directly from farm to consumer and (2) growing imports of fresh produce from developing countries. The third trend is driven by the combined effects of changing consumer attitudes and government oversight. These drivers are forcing development of accountability systems on firms along the entire supply chain to ensure that fresh produce (and subsequent processed products of which it is a component) is safe and nutritious.

Most firms in the industry possess an *internal* traceability system for regulatory compliance and inventory control reasons. The

growing adoption of information technology systems such as ERP systems, and advances in tracking technology, such as mobile scanners/readers and voice-picking system has helped to streamline internal traceability, and the costs of implementing these systems have decreased significantly in recent years (Cook 2011). The standardized format of products in this industry (the "case") means that the essential tools for identifying products are common to the entire supply chain.

Verification of data and company practices in the industry is generally conducted by third party auditors, with the costs borne by industry. There is significant redundancy in this system as data verification is often duplicated, resulting in recent efforts to standardize verification procedures (Produce Traceability Initiative 2015).

Industry-wide interoperability. Traceability in the fresh produce industry has improved greatly since the creation of the produce traceability initiative (PTI) in 2006. Formed jointly by 4 major industry associations (Canadian Produce Marketing Association, GS1 US, Produce Marketing Association, United Fresh Produce Association), PTI is mandated with improving current produce trace-back procedures while developing a globally standardized, electronic-based industry traceability system (Produce Traceability Initiative 2011).

The PTI is working to establish *external* industry-level interoperable traceability by building on firms' internal traceability systems in 2 ways: (1) establishing a common nomenclature for product identification as well as a common numerical identification system for each product (the Global Trade Item Number [GTIN]), and (2) requiring that each firm track 2 common pieces of information (the GTIN and the lot number) as each case of produce moves through the supply chain. The system is facilitated by the fact that every firm in the supply chain handles a standardized unit of product—the shipping "case"—which is the level at which traceability currently occurs (Produce Traceability Initiative 2011). This allows each firm in the supply chain to scan each case and retain the encoded information in their computer systems. While there is no central database that holds information for the entire supply chain, firms search their own internal traceability systems to retrieve information on where the case originated, and where it was shipped to (the "one-back, one-forward" protocol; Produce Traceability Initiative 2011). The electronic format and supply chain standardization of this information makes information retrieval relatively fast. The "case" facilitates traceability standardization.

PTI is organized by a Leadership Council (LC) that represents every sector of supply chains. The Council has an Executive Committee (executives from associations), LC co-chairs, and representatives from each supply chain role. The LC has implemented several industry working groups that primarily focus on implementation of traceability and addressing technology challenges. The PTI also engages in industry-wide communication. These activities were undertaken with individuals from each of the administering organizations who were charged with creating momentum for change across the industry by inspiring other sectors to follow a similar milestone-based approach.

In forging a framework developed collaboratively with supply chain stakeholders, to motivate and enable firms across the entire fresh food category to modify their business processes, PTI engaged a heterogeneous group of industry stakeholders around a contentious and often misunderstood topic. This has led many to view PTI as an excellent model of future engagement with industry, NGOs, and government.

Pharmaceuticals

The global pharmaceuticals industry generates over $300 billion in annual revenue and produces thousands of different products (WHO 2015). Although demand for pharmaceuticals of all types is global, the supply side of the industry is relatively consolidated. The 10 largest firms, which account for over 30% of the global market, are all based in North America and Europe (WHO 2015). The industry is also highly regulated, with more than 50 countries having enacted pharmaceutical product serialization laws, and various government agencies, such as U.S.FDA, have been given authority to regulate the industry (CSC 2015).

The main driver of traceability in the pharmaceuticals industry is government regulation, ostensibly designed to protect patient safety. Changing market structure (for example, significant growth in internet sales of pharmaceuticals), along with increases in the types and volume of drugs manufactured and sold is also driving a need for more effective traceability. Drug counterfeiting poses a significant health risk and is rampant in the industry, and while an increasing number of governments are taking tracing and serialization regulation in the pharmaceuticals industry seriously, laws that are enacted differ significantly among countries, thus creating obstacles for the global supply chain. Some laws also require independent and often competing organizations to work together and share information to ensure life- cycle traceability, which is an added barrier to implementation (Murthy and others 2008). In addition, the fact that pharmaceuticals are often part of extremely long and complex supply chains (being bought, stored, and resold several times before making it to the point of sale) intensifies the difficulties faced in implementing traceability, especially in the absence of global standards (Parma IQ 2014).

There are several emerging models for traceability in the pharmaceuticals industry, the choice of which depends on market and country specific characteristics (GS1 2010a):

The "one-up, one-down" model is perhaps the most basic traceability model, and is similar to the requirements in place for ensuring traceability for food products in the U.S. and the EU. In this model each firm in the supply chain keeps a record containing the product identifiers and characteristics, from whom the product was received, and to whom it was sent. Although it is possible for the product to be traced throughout the entire supply chain using this model, the fact that there is no single repository for tracing information means that the speed at which products may be traced is often not as fast as other more comprehensive approaches (Murthy and others 2008).

The "pedigree" model for traceability requires that a record containing information on product identification, characteristics, and any change of ownership accompanies the product (either physically or electronically) throughout the supply chain. For example, the California e-Pedigree Law, which came into effect in 2015, requires an electronic pedigree to accompany all prescription drug distributions in California starting from the manufacturer up to the point of sale. A pedigree in this case is an electronic record of all transactions that result in a change of ownership, and the law requires that these records be maintained using an interoperable, electronic system that ensures compatibility at all stages of the supply chain (GS1 2012a).

The "point of dispense authentication" model is a process that determines whether a product is actually what it purports to be at the point of sale. For example, Turkish law requires drug manufacturers to uniquely identify their products using (GTINs) and lot/batch numbers, and to upload a list of these numbers to a

central government database. The drugs are then authenticated at the point of sale by checking human- and machine-readable identifications on product packaging against the central database (Axway 2011).

The "distributed network track and trace" model requires that all firms who produce, buy, sell, store, or otherwise impact a product in the supply chain publish key data that are accessible to other authorized parties in the supply chain as well as government regulators (GS1 2012b). Information is published to a "cloud" and permissions are granted by the owners of the data to determine who has access. This model is perhaps the most advanced traceability architecture but also the most complex to implement.

Industry-wide interoperability. Compared to automotive and fresh produce, the pharmaceutical industry is not as advanced in the development of global traceability solutions. Most approaches remain national. Global solutions being explored are mainly shepherded through the GS1 organization and the use of their unique product identification systems.

Given that the most fundamental concern for effective global traceability in the healthcare industry is the use of a unique product identification, the use of a single organization to assign and record that identification reduces complexity. However, implementing global traceability in the pharmaceuticals industry is extremely challenging given supply chain complexities, the disparity in regulations among countries, and the variable speed at which government regulations are changing.

The U.S. provides an example of changes in national regulations affecting the pharmaceuticals industry. The (DSCSA) was signed into law on November 27, 2013, as Title II of the Drug Quality and Security Act of 2013. DSCSA creates national requirements for tracing pharmaceuticals across the supply chain, preempting state-level traceability requirements. The DSCSA includes provisions for product identification, tracing and verification; detection and response; and notification. The DSCSA act requires manufacturers, re-packagers, and wholesalers to be able to securely exchange electronic or paper-based lot-level transaction information (TI), histories (TH), and statements (TS) for all shipments. Transaction records include 3 components: (1) History; (2) Information; (3) and Statement (Staver 2015).

- Transaction history (TH): identifies who has owned the product.
  - Single document starting with manufacturer, includes TI for each transaction going back to the manufacturer
    - Number of containers (units shipped)
    - Lot number
    - Transaction date
    - Date of shipment
    - Business name/address of seller
    - Business name/address of buyer
  - Special versions of TH possible for direct purchase wholesale distribution operations
  - Electronic or paper (initially) and Electronic format required starting in 2017

- TI: describes the product (NDC, lot number, and so on).
  - NDC
  - Product name
  - Strength
  - Dosage form
  - Container size

- Number of containers
- Lot number (optional in certain scenarios)
- Transaction date (business transaction)
- Shipment date (if >24 hours from transaction date)
- Transfer from party (business name and address)
- Transfer To party (business name and address)
- Wholesaler contact information (for drop shipment)

- Transaction statement (TS): attests to the fact that the transaction is correct and that the TI is accurate. The TS also attests to the fact that transferring ownership/transfer was accurate.
  - Is authorized and registered
  - Received product from authorized, registered party
  - Received TI and a transaction statement from the previous owner
  - Did not knowingly ship suspect or illegitimate product
  - Had systems and processes in place to comply with verification requirements
  - Did not knowingly provide false TI
  - Did not knowingly alter the TH

Financial

Financial transactions range widely in size and location. Financial transactions are regularly aggregated or disaggregated at multiple points along the chain. These factors, along with finance being arguably the world's most global and intertwined industry, make the tracing and monitoring of transactions highly complex and challenging.

That the global financial industry is typified by a wide range in the size, geographic footprint, commercial interactions, and relationships, along with marked differences in the power and authority of individual organizations, makes generalizations extremely difficult. Drivers of more effective traceability include growth in personal electronic banking, a plethora of new products and target markets, and fraud. These factors, along with widening demand for government and institutional oversight of the financial industry, have increased the need to monitor the validity and legality of financial transactions to counter fraudulent dealings. Key to enabling the tracking and tracing of financial transactions has been the development of a standardized ontology or data taxonomy to support the mandatory exchange of information in ways that result in full-chain traceability. Three developments in particular have resulted in the interoperable traceability systems that now typify the financial industry.

Industry-wide interoperability. The most standardized element of financial transactions that result in efficient and effective interoperable traceability is Society for Worldwide Interbank Financial Telecommunication (SWIFT). Established in 1973 with the support of 239 banks operating in 15 countries, SWIFT acts an international clearinghouse for wire transfer messaging. SWIFT does not transfer funds, but standardizes the messages that go from one bank to another. This minimizes errors and enhances the rigor of data exchanged. The system's standardization is maintained and enforced by this global entity determining what everyone else must do. Messaging services include SWIFTNet, an advanced Internet protocol-based platform that offers 4 complementary messaging services: FIN, InterAct, FileAct, and Browse (SWIFT 2011). SWIFTNet is a single-window environment that supports secure and reliable straight-through processing (STP) with standards and technical interoperability. FIN enables exchange of messages formatted with traditional SWIFT MT standards, and works in

store-and-forward mode. InterAct enables exchange of messages formatted with XML-based SWIFT MX standards, and supports real-time query-and-response as well as store-and-forward messaging. Browsing is enabled via standard Internet technologies and protocols such as HTTP-S and HTML. The organization also has a Distributed Architecture program which enabled it to introduce customer messaging zones to support data privacy and advance overall security and resilience (SWIFT 2014).

Two additional elements provide governance and oversight on best practices that support banking in general and specifically help curb money laundering: the Financial Action Task Force (FATF) and the Basel Committee for Banking Supervision (BCBS).

The FATF is an inter-governmental body established in 1989 by the Ministers of its Member jurisdictions. The FATF sets the global standards for combating financial crimes and threats to the integrity of the international financial system (FATF 2015). The FATF Standards are comprised of FATF Recommendations (FATF 2012), Interpretive Notes for the 40 listed recommendations, and applicable definitions. The Standards are endorsed by 180 countries and universally recognized as the international standard for anti-money laundering and countermeasures against terrorism financing. Given the diversity of legal, administrative, and operational frameworks and different financial systems, implementation of their recommendations is done by each country (FATF 2015), so is less standardized than SWIFT. However, a country review showing elements of noncompliance has serious ramifications, to the point that if a country is placed on a noncooperative list, then financial transactions must be curtailed. The FATF has Guidance, Best Practices, and other advice to help countries implement the standards, and it reviews its members' progress in implementing necessary measures, facilitated by defined methodology for conducting assessments of technical compliance with its recommendations and outcomes-based review of the level of effectiveness the financing of terrorism systems (FATF 2013).

The Basel Committee's mandate is to strengthen the regulation, supervision, and practices of banks worldwide to enhance financial stability. This is accomplished through the provision of a forum for exchanging information on supervisory matters and formulating supervisory standards and guidelines (BIS 2015). The BCBS also issues standards that each country must implement, though unlike FATF it does not have strong enforcement capabilities. Instead, its role is to help motivate a country or individual financial institution to adhere to global standards, by fostering a negative stigma around noncompliance. Fear of the economic impact that being labeled noncompliant would have on the fortunes of a country or individual business has aided the implementation and adherence to standardized reporting and data sharing systems. The Basel Committee's international regulatory framework for banks is comprised of a number of documents addressing capital and liquidity: Basel III: Capital, Liquidity Coverage Ration, and Net Stable Funding Ratio (BIS 2015).

Comparative summary of capabilities, gaps, and determining factors

The remaining part of this discussion focuses on common practices employed by the seafood industry relative to standard-driven practices developed by the industries summarized above. The discussion is also briefly summarized in Table 5.

All industries have privacy and security concerns with respect to intellectual property and proprietary data. The seafood industry is no exception. The complex, diverse, dynamic, and risky nature of the industry generates tremendous amounts and variety of data and information. The same factors increase the pressure on firms to use that information to competitive advantage. This contributes to an industry culture perceived as secretive and having a low level of trust between firms (Future of Fish 2014). This can often result in "information silos" where information is stored but not used or shared. Seafood firms are also part of multiple and complex supply chains and the risk of a data breach may compel firms to limit the sharing of information other than that which is mandated by government regulation or market contract, even though the benefits of data sharing and collaboration may benefit all firms along the chain (Sterling and others 2015). Because security is paramount, data encryption by seafood industry firms is commonly used (Future of Fish 2014). Any traceability architecture will need a high level of security, and that security will need to be demonstrated. Early adopters can be incentivized to demonstrate that the system is trustworthy in order to attract new firms and build trust among its users.

Although data storage of traceability-related information now occurs at the firm level, the main benefit to maintaining data in a system that allows electronic queries from permitted users is the speed with which an item can be traced. It is not, however, desirable to store data in a central database, such as in the Turkish pharmaceuticals industry (see Section "Pharmaceuticals"), due to security concerns (Bhatt and others 2013b; Future of Fish 2014).

In contrast to many industries with relatively mature traceability systems, data measurement and recording practices in the seafood industry are often outdated, relying on pen and paper or other recording techniques with significant opportunity for human error. These errors may be magnified through the supply chain if the same information is re-recorded at each node (Future of Fish 2014). Although there are benefits to implementing technologically advanced systems such as touch screen computers, scanners, and automatic label printers, the costs of implementing and maintaining more advanced equipment, will mean that many firms will still rely on paper-based systems.

Product identification. Product identification is critical to traceability as it serves as the key link between the physical product and its associated information flow (Zhang and Bhatt 2014). The fresh produce industry shares many of the same characteristics as the seafood industry (size, fragmentation, large number of products, global supply chain), but the standardization of a traceable unit (the "case") simplifies the implementation of an interoperable traceability system.

Although the automotive industry has led the way in identifying products by printing each component of a vehicle with an identification code, and the pharmaceutical industry uses barcodes containing a unique identifier, there is no common model for the seafood industry. Due to the global nature of the industry, a universally unique identification number is considered essential for advancing the success of traceability (Sterling and others 2015). Although there is a range of companies that provide these "numbers," a single organization that would maintain a global registry could reduce the complexity and advance the adoption of traceability systems. The impact of not having a well-governed registry system is evident in the traceability systems that typify much of the global pharmaceutical industry, an environment where public-health-supporting activities (drug supply) are similar to managing the flow of food products.

Data validation. Validation of data is a critical concern for implementing whole chain traceability. The automotive and finance industries have developed highly effective and efficient means of data validation. If shared information is not transparent and

Table 5–Traceability "best" practices across industries recognized as global leaders in traceability compared with the common practices of the seafood industry, and their GAPS, needs, and issues.

	Industry best practices				Common practices	Gaps, needs, and issues
Process	Automotive industry	Fresh produce industry	Pharmaceuticals industry	Finance industry	Seafood industry	Seafood industry
Product identification	Direct part marking (DPM). Every part is marked with a code.	Labels with machine- and human-readable data affixed to each case.	Unique GTIN, lot number, expiration date contained in bar code on each package.	SWIFT code ensures standardized identification of all transactions occurring between financial institutions.	Wide range of practices— barcodes, stamps, hand-written labels.	Challenge in managing/integrating multiple IDs (POs, work orders, packing orders, etc.) that get generated during critical tracking events. Major logistic issues due to seafood granularity and 'lot' aggregation issues at every level.
Data addition	Each component of a subassembly scanned on the production line. Subassembly identifier linked to components using ERP system.	Each firm enters and stores additional data which are linked to a GTIN and lot number.	California e-pedigree: record of all handlers of drug accompanies product. Data added at each node.	Each firm inputs data according to global SWIFT standards.	Wide range of practices including electronic and paper based systems.	Major granularity issues across the supply chain. Mid-chain black holes due to combining 'lots'. Challenging to add data in a fast-moving fresh product processing line. Other product forms less challenging.
Data partition	ERP system generates automatic reports and handles electronic queries.	Industry standard: one-back, one-forward protocol GTIN and lot number tracked by each firm.	Electronic ERP systems facilitate mandatory data partition.	Enforced by mandatory adherence to industry standards.	Manual partition in the case of a recall or mock recall. Automated systems rare.	Government-issued fish tickets include core traceability information. Seafood industry does organize data that can be easily shared down the value chain. Certain KDEs are required by the retailer (country of origin, species etc.). Data are partitioned at producer level and again at each value chain node.
Data storage	Each firm stores its own data. Large amount of data-cloud-storage used.	Each firm stores its own data in electronic format.	Turkey: central government database. California: data copy stored by each firm.	Each financial institution responsible for storing granular data. SWIFT systems stores aggregated data in central databases.	Wide range of practices. Storage in firm's computer systems or file cabinets. Information silos are common.	Data input and access may be far slower than real time, especially if paper-based. Fish ticket systems mostly paper-based. May take years to enter logbook data. Need lower cost ERP systems for small companies. Lack of access to infrastructure and human capital (skills) in remote areas of the world.
Data transmission	Electronic messaging facilitated by ERP system.	Electronic messaging of GTIN, lot number, date, and firm identification.	Data transmitted with product (California), or data in electronic form sent to central database (Turkey).	Standardized electronic encrypted messaging. Records linked to financial transactions.	Some electronic messaging but interoperability a big problem. Data often sent physically with the product.	Most firms as well as the value chains lack systems, infrastructure and access to key communication technologies.

(Continued)

Table 5–Continued.

Process	Industry best practices				Common practices	Gaps, needs, and issues
	Automotive industry	Fresh produce industry	Pharmaceuticals industry	Finance industry	Seafood industry	Seafood industry
Data security and access	Manufacturer has power over chain and can initiate data requests. Secure storage.	Secure storage at each firm, can be queried by the firm for a recall.	Secure government database, or each handler can track product back.	Secure electronic. Transfer requests authorized prior to money exchanged between corresponding accounts.	Data may not be secure if paper based. Encryption of electronic data common. In fragmented seafood value chains data may be closely guarded.	Seafood industry will not trust a traceability system without testing and validating security systems. Concerned that cloud portals may provide access into an entire firm's database. Use early adopters to test and demonstrate the system. The level of security should reflect the degree of risk.
Data collection and measurement	Electronic scanners read DPM codes.	Barcode scanners and integration with ERP system.	Barcode scanners commonly used.	Standardized electronic systems that incorporate mandatory protocols.	Wide range of practices including some bar code and other devise scanners. Manual data entry and measurement common.	Reliance on physical measurement and recording of weights, temperatures etc. may lead to measurement and transcription error. Unclear what needs to be standardized? Need for standardizing species name—especially given merging of common names and species mislabeling and fraud. Retailers moving to placing the species and common name of fish on the packaging.
Data validation	Built in checks to ERP system.	Third party auditors are the norm.	Push towards globally unique identifiers and serialization.	Transaction records and verifications audited by third party auditors, Checks built into proprietary systems.	Wide range of practices. Third party auditors common. Manual double-checking of data. Some use of electronic systems with built-in validation. Primary processor may validate catch data, Enforcement agencies may also validate catch data.	Primary producer data may be difficult to validate. In the seafood industry there is a need for different classes of data validation including authenticating vessels and processors (typically government), certifying the data process used by harvesters and processors (third parties), and data validation using double-checking or computer algorithms.

trustworthy, the market will discount the information and the value of the product it represents (Future of Fish 2014). Data verification occurs throughout the seafood supply chain in a variety of ways: for example, double-checking manual data entries through paper audits either internally or through a third-party inspector. Environmental certifications or health and safety rules can often drive this process and result in selected firms being audited multiple times with the costs borne by the firm. Some firms do internal validation by using mock product recalls to identify data gaps and sources of error.

Lack of uniform requirements and standards for collecting and sharing information can significantly impede interoperability within the firm or across the value chain (Sterling and others 2015). Firms fulfill contractual and regulatory data sharing and storage requirements using diverse approaches, which impede the speed with which products can be traced, increase the opportunity for errors, and increase the overall cost of meeting traceability requirements. Indeed, defining what constitutes a traceable item varies widely in the industry (Sterling and others 2015). In some situations a single fish constitutes a traceable item while in other situations a shipping container full of fish from various sources is the traceable aggregate "lot," "batch," or "item." The definition of "lots" as a traceable item is widely variable in the industry. Processors may combine catch from multiple vessels into the same "lot" leading to a loss of detailed information that may be critical for effective traceability (Future of Fish 2014). Distributors or shippers may then combine several such "lots" into a larger aggregate "lot," potentially leading to further loss of detailed information or a midchain "black hole" (Future of Fish 2014). There are major granularity or "lot" issues in the seafood industry and standardization would be a key strategy in addressing the issue. In general, the seafood industry does not organize data into forms that may be shared easily up and down the value chain. Standardized protocols for data sharing, including the form which data take, and the standardization of definitions such as "lots," are essential for successful whole-chain traceability in the seafood industry (Zhang and others 2014; Global Food Traceability Centre 2015).

Comparative state of traceability in the global seafood industry

Although the global seafood industry shares characteristics with the industries highlighted in our case studies, there are also major differences that influence the design and implementation of a technology architecture suited to enabling global interoperable traceability. The size, diversity, and geographic distribution of the seafood industry compared to the automotive, fresh produce, pharmaceuticals, and finance industries suggests that data recording, storage, and transmission capabilities will be significant barriers to developing efficient and effective traceability systems. Fresh produce shares 2 characteristics with seafood: perishability (which limits storability) and seasonality (which creates supply challenges) (Cook 2011). Coupled with increasing consumer demand for year-round, high-quality fresh produce and the introduction of mandatory food safety traceability requirements (such as the U.S. Food Safety Modernization Act of 2010), the challenges of implementing global traceability for both produce and seafood are significant.

The conditions required to produce automotive parts or pharmaceutical components are generally restricted to areas of the globe where infrastructure is relatively well developed. Production of fresh produce is limited to regions where growing conditions are suitable and reasonably close to major markets to overcome prob-

lems caused by the perishable nature of these products. Financial organizations are typically located in urban centers. Conversely, seafood is produced, processed, and exported from every corner of the world using a wide range of production practices reflecting the characteristics of the harvested species. The diversity of economic, human, technical, environmental, cultural, and resource management systems is also more acute in the seafood than in the automotive, fresh produce, pharmaceuticals, and finance industries. In many of the seafood production regions of the world, the "enabling conditions" for effective traceability, including adequate technological and political infrastructure, are not present. The rapidly growing aquaculture sector, which represents half of all seafood now produced, may help in driving traceability standards, although most aquaculture occurs in developing countries.

The complexity of seafood industry supply chains is another significant consideration in designing a technology architecture suited to enabling global interoperable traceability. In contrast to the automotive and pharmaceuticals industries, in particular, individual seafood firms in the supply chain may range from household-level producers to large multinational corporations. The internal systems that enable traceability range from simple paper-based record-keeping and data storage to complex ERP systems that are automated and integrated with a firm's business operations. This creates major challenges in designing interoperable systems that can interface with such a wide range of technologies. That this is being achieved in the fresh produce industry, albeit at differing paces around the world, is encouraging.

Another characteristic of the seafood industry is the diversity of species, products, and product forms that are harvested, processed, and traded. In the fresh produce industry all produce is fresh and must be kept in reasonably similar conditions throughout the supply chain. With a "case" as the common entity for produce, traceability is simplified. Further, because visual identification of a produce item is typically straightforward, often even after some processing has occurred, produce traceability is simplified. In contrast, in the seafood industry products range from whole fish to products where whole fish (possibly from different sources) have been processed, transformed, and "disaggregated" and mixed with other ingredients that also need to be traced. Some products may reach the consumer having never been frozen, while other products are stored in cold storage for months or years before reaching the consumer. Still other products may be cooked and vacuum-packed, or packaged in cans and retort containers. Some products are more likely to have the potential for food safety concerns (such as histamine generation) than others. The requirements for the design of a global traceability architecture will need to reflect the diversity of product types and the highly perishable nature of refrigerated product.

The diversity of the industry is also reflected by the extreme "granularity" of the data the industry generates, including a wide range of temporal, physical, and geographic data. This granularity issue impacts most of the key processes including product identification, data addition, and data collection and management. For example, what geographic scope is acceptable in representing the origin of harvests? What date ranges for production are acceptable in meeting a traceability standard, for example, a single production run, daily production, weekly, monthly, biannual, yearly? How many raw material lots of different origins can be merged into a production lot but still maintain acceptable traceability levels for addressing food safety, fraud, or product quality? While these considerations are not necessarily unique to seafood, their dynamics are.

A common insight from the comparative analysis is the degree to which a well-governed process led by industry leaders has an influence on achieving the standardization required to enable effective global interoperable traceability. While legislation was a motivation for change in all of the industries discussed, the most impactful influence for establishing the means of effective interoperable information systems and traceability typically stemmed from individual firms proactively coalescing around a pre-competitive issue that may not itself have been explicitly related to traceability. As the initiatives progressed and momentum increased, the initiatives encompassed a widening array of industry stakeholders and focused on more ambitious objectives. This produced a steadily evolving foundation that benefited the wider industry. The same evolving foundation of tools, technologies, and capabilities enabled individual businesses, and the supply chains in which they operated, to create market opportunities, increase operational efficiency, and manage risk in ways that would be unattainable without the existence of global interoperable information and communication technologies.

Research Conclusions and Implications

The final chapter of this Issues Brief presents a summary of research findings and implications associated with designing a technology architecture to enable interoperable seafood traceability. Given the critical importance of engaging industry stakeholders in the development of information and communication systems this section concludes by recommending a strategy for engaging the seafood industry in the design of interoperable traceability.

Summary of findings

Traceability is enabled through the collection, management, and sharing of information. The Issues Brief discussed determinants that are important to the collection, management, and sharing of traceability-related information within firms, along supply chains, and across industries. Each discussion focused on a topic central to enabling interoperable information and communication. Two levels of interoperability were discussed: syntactic and semantic. Syntactic interoperability enables the exchange of standardized data and reporting. This is the foundation that enables interoperability to occur. Semantic interoperability is the ability for internal and external systems to converse in a common language. This provides businesses with the capability to utilize data in a myriad of ways to create and capture value. The ability to translate interoperability into commercial benefit is partly determined by the structure and nature of the value chain(s) in which businesses operate.

The research identified a wide range of practices employed by the seafood industry as well as more standardized practices employed by industries that are global leaders in developing traceability systems and enabling "architectures." The research also showed that the seafood industry is evolving, particularly with respect to the role of information in supporting it success. The research identified key gaps, needs, and challenges for the industry, both within firms and along supply chains.

The Issues Brief also discussed how seafood is a commodity that is experiencing constant and increased surveillance for regulatory compliance. As occurring in the U.S., such surveillance often results in additional regulations. In the United States the regulations are primarily being implemented by FDA, but also by the National Marine Fisheries Service/NOAA (NMFS/NOAA) which is preparing a Proposed Rule for traceability. As has occurred in other industries (such as automotive and finance) increasingly stringent compliance standards mean that interoperable traceability functions must reflect the needs of industry and regulators. Inter- and intra-company sharing of KDEs is key to achieving this interoperability as well as controlling food safety, sustainability, fraud, and the efficient management of product and ingredients for added value. KDEs are also key to the global regulation of seafood. This means that the relative importance of specific KDEs differs and can be ranked by the extent to which businesses utilize interoperable systems to derive economic value. A lack of standardized KDEs negatively impacts global seafood traceability.

The research illustrates why the development of a common ontology is critical to the development of interoperable technology systems. The development of a common ontology is particularly critical for enabling the implementation of effective whole-chain traceability in such a diverse and complex industry as seafood. An ontology cannot be developed in isolation. It must take into account the technologies that enable traceability systems to operate and how these technologies are utilized by commercial businesses.

As occurred in other industries, achieving the outcomes required to enable interoperable traceability will require extensive stakeholder input. The starting point is for key industry leaders to coalesce around a vision and activities that evolve. Yet the familiarity of seafood stakeholders with issues such as KDEs and ontologies and the importance of their role in interoperable traceability is limited. Unless addressed, this gap in awareness and understanding will prevent informed discussions from occurring and perpetuate the current situation in seafood compared to other industries.

Value chain implications

An important implication raised by the research is that inefficient and ineffective flow of products through a supply chain is caused by failings in the information flow, which are not just caused by technological deficiency. Inefficient and ineffective product flow can typically be traced to weaknesses in intra- and inter-firm relationships. These are caused by a lack of strategic alignment, operational understanding, trust, commitment, benefit sharing, and, ultimately, collaboration. In terms of traceability systems, these result in a reluctance to invest in the necessary assets or skills, or an unwillingness to share sensitive information.

Most benefits of implementing a communication and information system are not within the control of a single company in the chain, and, accordingly, achieving the expected outcomes is dependent upon the behavior of other chain members, not just the sophistication of the technology (Sanfiel–Fumero and others 2012; Sterling and others 2015). The lower the uncertainty over the behavior of others, the greater the confidence a firm will have that its investment in establishing and operating the system will deliver the anticipated return on that investment. Indeed, the stronger relationships are across the whole chain, the more ambitious those investments can be in looking to generate higher and longer term returns. Thus, inter-firm relationships will affect the willingness of firms to invest in and operate systems, and their expectations as to what returns the system should deliver.

Accordingly, the development of technology architecture should provide flexible options which:

(1) can be selected and later developed to reflect the variable and dynamic nature of inter-firm relationships (from fragmented, through cooperative and coordinated, to collaborative—sections "Assessment of Current Gaps Versus Realizable Opportunities" and "Comparative Summary of Capabilities, Gaps, and Determining Factors," along with Figure 4), so that firms have choices appropriate to their

current state, but which can easily extend that system as collaboration deepens;

(2) allow chains to agree and pursue a collective strategy over what outcomes are desired and realistic, from "legal compliance only," through different combinations of operational efficiencies, business risk mitigation, and market access (section "Comparative Summary of Capabilities, Gaps, and Determining Factors" and Figure 2), and

(3) include guidance on how to select options within the architecture which are most suitable for the current relationships within a particular chain, and its initial objectives (section "Comparative Summary of Capabilities, Gaps, and Determining Factors").

Inter-firm relationships and their impact on traceability systems

Supply chain integration, such as through traceability systems, require individual business functions and processes within companies and across chains to work together more closely (Spekman and others 1998). Indeed, some argue that effective traceability relies more on the extent of collaboration among supply chain participants than on the IT systems that support it (Spekman and others 1998), because however sophisticated the system is, it depends upon the willingness of participants to share information. A firm's readiness to collaborate depends on trust, which is generated by confidence resulting from past experiences and, in part, manifests itself as a willingness to take a risk by relying on another's competence (Spekman and others 1998). Conversely, asymmetric power relations, for example from unequal dependence, often deter trust, by reducing cooperative attitudes, destabilizing relationships, and increasing the likelihood of opportunistic behavior (Spekman and others 1998), either through suppliers switching customers or processors/retailers changing suppliers. Hence, divergent strategies, resources, and capabilities, asymmetric information, and opportunism all potentially contribute to reducing the effectiveness of information flow within a supply chain (Mason-Jones and Towill 1997; Canavari and others 2010), because information disclosure is seen as a loss of power (Berry and others 1994), and vulnerable chain members may fear that confidential information will be abused, to the benefit of their competitors (Vernède and others 2003).

In food sector supply chains, trust is often lacking, because in the highly competitive environment the strategies of downstream firms are often focused on choosing suppliers based on quality and cost alone, rather than other capacities such as their ability to form partnerships. In addition, typically, there is an imbalance in scale and power between small upstream suppliers and dominant processors/distributors and retailers. The previous discussions in this text illustrated the extent to which this situation exists in seafood. As a result, suppliers respond by trying to leverage their independence and information to maximize their own margins, even if that is at the expense of others within the chains in which they participate. These factors and attitudes combine to create a culture of transactional relationships and opportunism.

Implementing traceability systems is an effort to overcome these challenges. It favors a narrowing of supply bases and the building of stable, closer relationships. Yet, any reluctance to share information potentially impacts significantly on the effectiveness of traceability systems. There is greater uncertainty about how other chain members will act; for example, whether they will make investments in traceability systems or how they will operate them (Charlier and Valceschini 2006). For example, when relationships are weak, there is less confidence in the data that are added into systems by others in the chain (Choi and others 2008; Canavari and others 2010). In unstable chains, where members are liable to change, some systems may even become redundant (Banterle and Stranieri 2008).

Furthermore, while traceability can reduce transactional uncertainty between firms, it may also increase their bilateral dependency (Han and others 2006), counter-cultural to some firms. Finally, traceability systems and the resultant transparency with performance may alter the chain's governance (Banterle and Stranieri 2008), a prospect which may further deter those who already feel vulnerable within the chain from engaging in more elaborate systems, especially if they also feel that the traceability system is being imposed on upstream members without any resulting rewards (Canavari and others 2010).

Accordingly, firms should understand the relationships across the whole chain—and not just with their immediate suppliers and customers to establish the most appropriate direction and pace for increasing integration (Cox 1999; Maloni and Benton 2000); this is true specifically of investments in designing/selecting and implementing traceability systems (Cox 1999; Vernède and others 2003). Going along with this argument, the recent GFTC report "Assessing the Value and Role of Seafood Traceability from an Entire Value-Chain Perspective," Sterling and others (2015) adopted a classification developed by Value Chain Management International (2012) to assist chains in diagnosing the current state of their chains' relationships (Figure 7).

Consequently, a technology architecture must possess the ability to adapt to the dynamic forces that shape the relationships and capabilities that evolve between members of individual supply chains. The relationships and resulting interactions that occur between businesses at the time of having implemented traceability will invariably be different to the relationships, interactions, and resulting competencies that develop over time. This dynamism will include the potentially positive impact which collaborating in traceability can induce, where cooperating even just in a mandatory, compliance-only system may facilitate closer proactive relationships. This would result in greater trust and integration, leading to the involved businesses having more opportunities to utilize traceability and associated capabilities for competitive advantage. Hence, the attractiveness and take-up of any traceability architecture will increase the more it is able to accommodate the dynamic nature of inter-firm relationships.

Alignment of strategic objectives

The recent GFTC report (Sterling and others 2015) also identified 8 potential approaches/objectives for seafood traceability systems. The approach, applicable to all value chains, is "compliance-only." Dependent on the level of operational and strategic alignment existing between businesses that together form a value chain, the report described 6 further approaches that businesses could utilize traceability to mitigate risks, improve operational efficiencies, and gain market access. The 8th option, Best Practice, applies to value chains whose level of alignment would enable the involved business to utilize traceability to achieve all 3 objectives (Figure 8). For example, some firms use data not only for mandatory chain-wide traceability for food safety purposes, but also to improve efficiency or product quality (Jansen-Vullers and others 2003) through greater control of processes within and among firms, and thus creating value and competitive advantage (Van der Vorst 2004).

This means that, in order to achieve their expectations and share in the resultant benefits, chain participants who are investing in and then operating a traceability system should agree which of the 8 strategies they are collectively pursuing, and select and operate the system accordingly. Without such collective agreement, investment and implementation is likely to be inconsistent, and/or the technology selected may not be appropriate. Indeed, the anticipation of those problems prevents the investment being made in the first place.

There should also be a connection between participants' capabilities and the current state of their relationships, with the strategy pursued, and the technology adopted. For example, in one recent study, the weak relationships in a Swedish cod chain meant that a compliance-only strategy was deemed the limit on what could be achieved (Ringsberg 2015). Conversely, implementation of additional, voluntary standards involves a wider reorganization (Banterle and Stranieri 2008) and strategic changes (Souza-Monteiro and Caswell 2004). This is significant because it is such "beyond compliance" systems which offer greater prospects of higher returns on investment (Sterling and others 2015). These more ambitious strategies require partners to work more closely together (Sanfiel-Fumero and others 2012), which increases their inter-dependency, for which trust is a prerequisite. Accordingly, an understanding of the current state of the chain, and its consistency with the strategy and technology adopted, is even more critical when the aspiration of some or all the participants is to create additional value from the traceability system by including functionality exceeding regulatory requirements.

Implications in designing a technology architecture

The major considerations that flow from the research and which should be factored into the design of a technology architecture requirement to enable global interoperable seafood traceability are summarized below. The considerations are not arranged in order of importance.

Designing an industry traceability architecture requires a clear understanding of practices and processes used by industry for both internal and external traceability, as well as the universe of practices that could be employed in designing a global system.

Every process is key to developing a successful global architecture. The selected practices that bring these processes to life must be intelligently crafted. It is paramount that architectures be built on practices that efficiently align these processes—internally and externally.

The diversity, complexity, "dimensionality," and information needs of the seafood industry pose major challenges compared to other industries in developing a global architecture. The architecture must "embrace" these complexities without creating inefficiencies or "suffocating" users with excessive rules, standards, practices, and requirements.

The leading traceability industries have standards (voluntary or mandatory) that guide the design of traceability systems to bring value (maximize profits, reduce risks, and/or minimize costs) to the entire supply chain. These standards may directly have an impact on how firms develop internal information systems as well as affect the design of external systems.

The definition of "lots" as a traceable item is widely variable in the seafood industry. In general, the seafood industry does not organize production output or data into standard formats. Standardized protocols for data measurement, data sharing, and standardization of types of lots are essential for successful whole-chain traceability.

Although traceability systems in many industries begin by addressing safety issues, they evolve to address a wider range of needs including fraud, waste, and efficiencies in production and marketing.

Linking internal traceability with external traceability is a key challenge for the seafood industry. Internal traceability systems need to be autonomous to meet the unique needs of thousands of individual companies, but need to have interoperable capacity so that outputs from internal systems can be "married" with an external traceability support system.

Any traceability architecture must have a very high level of security. That security will need to be demonstrated. Incentives will attract early adopters who can demonstrate that the system is effective and trustworthy. Potential incentives include market access, or loss when noncompliant, and reduced administrative or operational costs. Thus resulting in higher margins and profitability.

Almost universally, government and private sector markets will require more traceability information over time. This means that the architecture must be adaptive. For example, in order to accommodate the variable and dynamic nature of inter-firm relationships (from fragmented, through cooperative and coordinated, to collaborative), firms need choices that are not only appropriate to their current relationships, but also have an architecture that can accommodate greater information needs as future collaboration deepens.

In many of the seafood production regions of the globe, the "enabling conditions" for sophisticated traceability, including technological, educational, and "governance" infrastructures, are minimal. Given that seafood is sourced from many developing countries, a global architecture will need to recognize the constraints and support a diverse set of users.

The owners of the architecture should provide guidance on how to use the architecture so firms and chains can select "options" which are best suited to their needs given the relationships within a particular value chain. This can help firms, for example, in avoiding "over-reaching" given that value chains may expect outcomes which are unrealistic due to underlying problems in their relationships (lack of strategic alignment, commitment/longevity, trust, communication, incentivization, and so on); or to avoid "over-specifying," that is using aspects of a system or architectures that are more sophisticated than required to achieve company and/or chain objectives.

Inherent flexibility. Arguably the greatest research implication is that meeting the needs and practices of a diverse range of individual firms, supply chains, contractual arrangements, and regulatory regimes will rest on the technology architecture incorporating an inherent flexibility. The need for a flexible architecture is illustrated in Figure 4 which shows that the type, amount, and quality of traceability information will depend on both the state of the strategic alliances of the supply chain (Fragmented, Cooperative Coordinating, or Collaborative) and their strategic objectives (see Appendix 1 and Sterling and others 2015). The lightest shades in Figure 4 indicate the lowest level of traceability information needs, the darkest shades the highest needs. Fragmented chains generally need only limited information given the weak and transient relationships with other firms in the chain. The exception is when there is a regulatory requirement for traceability information which will force even fragmented chains to meet these requirements. In contrast, collaborative chains will have the strongest set of strategic objectives and alliances, as well as a high degree of

STRATEGIC OBJECTIVES	CURRENT STATE OF SEAFOOD SUPPLY CHAIN			
	FRAGMENTED	COOPERATIVE	COORDINATING	COLLABORATIVE
LEGAL COMPLIANCE				
MITIGATING BUSINESS RISK				
OPERATIONAL EFFICIENCIES				
MARKET ACCESS				

Figure 4–The type, amount, and quality of traceability information required by a supply chain (Value Chain Management International 2012).

trust. In parallel, collaborative firms also tend to have the best information systems and practices.

A key consideration is the practices that could allow a global architecture to meet these diverse needs, across firms and across value chains. One possibility is designing fixed "modules" or flexible "menus" of information options which could meet the needs of individual firms as well as the different classes of value chains. In the case of regulatory requirements, predetermined information modules could expedite the organization, retrieval, and sharing of traceability information with government(s) as well as other firms in the supply chain. As one moves along the strategic continuum, information-related contractual arrangements (or voluntary information-sharing arrangements) would become more comprehensive and complex. Some modules or menus could be predesigned to meet the needs of addressing higher-level strategic objectives. In other cases modules and supporting systems could be designed by traceability companies or a leading firm within the chain. Modules could also be designed to be additive and interconnected (like a jigsaw), so as collaboration deepens, and objectives become more extensive, modules would ideally integrate without having to re-start with a new system. Whatever the best set of strategies, the architecture will need to be flexible to meet the needs of a diverse and complex industry.

Self-diagnosis. A self-diagnosis tool would enable the businesses that together comprise a supply chain to utilize the benefits of a flexible technology architecture effectively at the outset and as the chain evolves. This ability would stem from the tool enabling businesses to make an informed assessment of the chain's capabilities and resources, which are generically known to contribute to the strength of inter-firm relationships, as well as the specific ones required to implement the various options within the traceability architecture. This would inform chain members' decisions on the nature of the traceability system most suited to their situation. The tool would cover strategy and behavior, including:

Strategic: Consistent, market-orientated competitive strategy across the chain (Bonney and others 2007), shared culture and values (Spekman and others 1998), compatible goals (Duffy and Fearne 2004), and durable relationships (Vernède and others 2003) across the chain.

Beyond 1 up 1 down: Understanding of the chain beyond immediate suppliers/customers (Horvath 2001).

Inter-dependence: Current value/volume of business and significant growth potential of that chain compared to others in which the firms participate; complementary physical and human resources (Spekman and others 1998), and commitment to working more closely with fewer suppliers/customers, rather than a focus on keeping lots of options open (Duffy and Fearne 2004).

Mutual investments: Investment in relationship-specific assets, and/or joint investments/risk-taking (Kanter 1994).

Trust: Cooperative attitude, and record of fulfilling obligations (Sharfman and others 2009) and resisting opportunistic behavior (Duffy and Fearne 2004), with conflicts being resolved constructively or having their causes pre-empted.

Incentive structures: Incentives aligned with strategy, rewarding investments and behavior, which create value and reward efficiency as appropriate (Bonney 2012).

Capacity to learn: Ambition and ability for continuous improvement (Duffy and Fearne 2004) to products, processes, and systems (Bonney and others 2007).

Capacity to act: Integrated decision-making and problem-solving (Duffy and Fearne 2004; including customers taking a proactive stance with suppliers, and suppliers being responsive to feedback (Hart 1995), and inter-firm team-working (Gold and others 2009), where joint working is institutionally embedded and is not dependent on specific personal relationships (Jayaram and others 2004).

Risk mitigation: Communication taking place at strategic and operational levels to improve transparency; reduce uncertainties, including ones about the exterior business environment as well as internal activities; exposing drivers of costs and pricing, and including personal as well as business issues (Fischer and others 2006).

Sustainability: Complementary social and environmental strategies (Vernede and others 2003; De Vleiger 2006).

Engaging with industry stakeholders

Through our research we identified the critical importance of engaging industry stakeholders in processes designed to enable interoperable information and communication systems. In an industry as complex and diverse as seafood, it is especially critical to develop an effective process of engaging industry stakeholders in meaningful discussions on the development of a technology architecture designed for enabling effective traceability. As has occurred in other sectors, specific engagement methods may differ according to stakeholders' involvement in the operation of a value chain, its technological capabilities or sophistication, and individuals' geographic location.

Although most companies have some level of traceability in place, some industry sub-sectors are further along in implementing traceability processes than others. Manual paper-based systems remain common, even though the involved businesses leave themselves vulnerable to human error and the potential for dangerous and costly mistakes. Paper-based systems or proprietary technologies that are unable to interact effectively limit the ability of businesses to profit from implementing traceability. The same also limits the ability of industry and regulators to verify data produced for compliance purposes.

Engaging an entire industry sector to modify business processes can only be successful if and when there are compelling industry drivers necessitating the change. This is perhaps the most important lesson from industry engagement activities that groups such as GS1 US have learned during its 40-year-long history working with many industries and supply chain stakeholders. The focus on traceability for the food industry continues to be influenced by government regulations, food safety concerns, and increased consumer pressure for accurate and complete product information.

Traceability is top-of-mind for the entire food industry, including packaged goods, retail grocery, and foodservice. Fresh food categories, however, are particularly vulnerable to the risks associated with lack of traceability in the case of market withdrawals, trace-back requests or product recalls. Over the past 10 years or so, the produce, seafood, meat and poultry, dairy, deli, and bakery sectors have been moving on separate, yet parallel, paths to understand how unique identification of product along with the standardized exchange of data between trading partners can improve supply chain visibility.

Given that the seafood sector generally misunderstands the concept of traceability, any engagement effort must begin with an extensive information- and awareness-raising process. Industry subsectors must be able to see past their differences by acquiring a level of mutual understanding regarding issues and challenges that do not presently exist. Increased awareness and understanding will enable more stakeholders, including partners on both the supply and demand side of business, trade associations, government, and solution providers, to agree on a common vision and goals based on industry drivers. The key to success, then, is focused on collaborative efforts toward defining and following a roadmap to implementing changes that enable industry to meet those goals.

Motivating and enabling whole-chain collaboration. To better track and trace food, and maximize the benefits of such, the industry needs collaboration and a holistic or whole-chain approach to the food supply chain. Whole-chain traceability is achieved when a company's internal data and processes, used within its own operations to track a product, are integrated into a larger system of external data exchange and business processes that take place between trading partners. Enabling whole-chain traceability involves linking internal proprietary traceability systems with external systems through the use of one global language of business across the entire supply chain. These standards enable trading partners in the global supply chain to talk to one another through the identification encoded in the various types of barcodes. By using the same standards to identify and capture data about products, companies can share specific product information more efficiently and accurately, ultimately benefitting both businesses and consumers.

In the fresh produce industry, for example, continually promoting the benefits of traceability proved critically important in driving implementation and engaging stakeholders to implementation challenges and successes. Case studies and pilot reports documented these issues and highlighted the numerous ways in which whole-chain traceability positively impacts the food supply chain. Four main industry-wide benefits surfaced throughout these success stories:

1. The ability to precisely locate potentially harmful products through value-chain visibility
2. Ensuring trustworthy product information and data quality
3. Reducing food waste
4. Enhancing operational efficiencies

Engagement methods. To determine effective means for engaging the seafood industry in the development of common interoperable traceability for the global seafood industry, the Engagement and Communications TAG distributed a comprehensive survey to a diverse group of 53 stakeholders around the world. Respondents included retailers, processors, distributors, the foodservice sector, and NGOs.

The responses highlight the need to provide a hands-on approach to education and training. Presented in Figure 5, the survey results indicate that real time/live workshops are considered a more effective means for developing a strong understanding of the issues, as opposed to printed materials or newsletters, and permit an interactive approach. It is important for industry to see examples of success in other industries through video case studies that highlight how they have benefited from the development of interoperable traceability systems. Learning what has worked in other industries would enable seafood industry stakeholders to clearly visualize how they can best address the challenges that lie ahead.

Key drivers behind why stakeholders would engage in designing a technology architecture that enables a global interoperable traceability relate to challenges and risk experienced by commercial businesses. These same factors often affect the overall seafood industry's sustainability. In order of importance, as shown by respondents' ranking of challenges on a scale of 1 to 5 (1 = *not at all important,* 5 = *very important*) the topics that will most engage industry in the development of an architecture for interoperable traceability are shown in Figure 6.

The majority of respondents expressed a willingness to engage in dialogue to develop a technology architecture suited to enabling interoperable traceability. More than half of respondents indicated a willingness to be active members in the process of developing such an architecture and to commit several days during the coming year to ensure that the seafood industry voice is heard throughout the development process.

Engagement strategies. The seafood industry is global and diverse, with no specific player representing a majority of the involved businesses. Each segment of the industry (for example, retail, wholesale seafood-specific distributors, broad-line distributors, and foodservice) includes publicly traded as well as privately held companies, with sales ranging from thousands to billions of
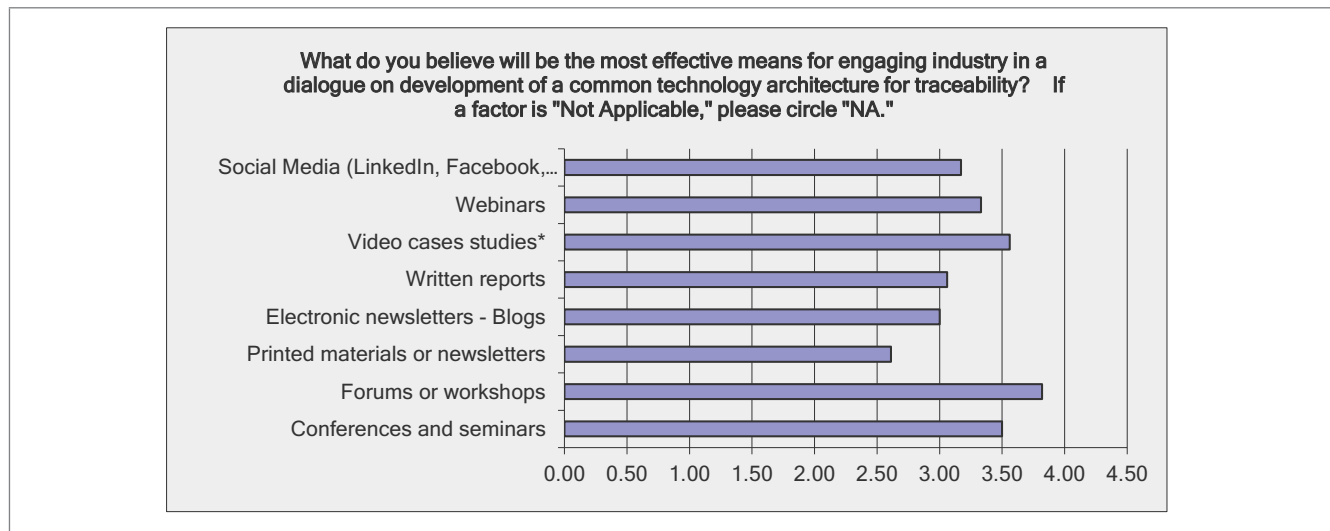
Figure 5–Effective means for engaging industry.
*Video case studies enable a far greater volume and depth of information to be conveyed about a real life scenario than possible through, for example, written materials. By engaging multiple senses among the viewing audience, videos enable strong emotional relationships to be established between the topic and the viewer(s), resulting in a greater likelihood of them acting upon the information presented.
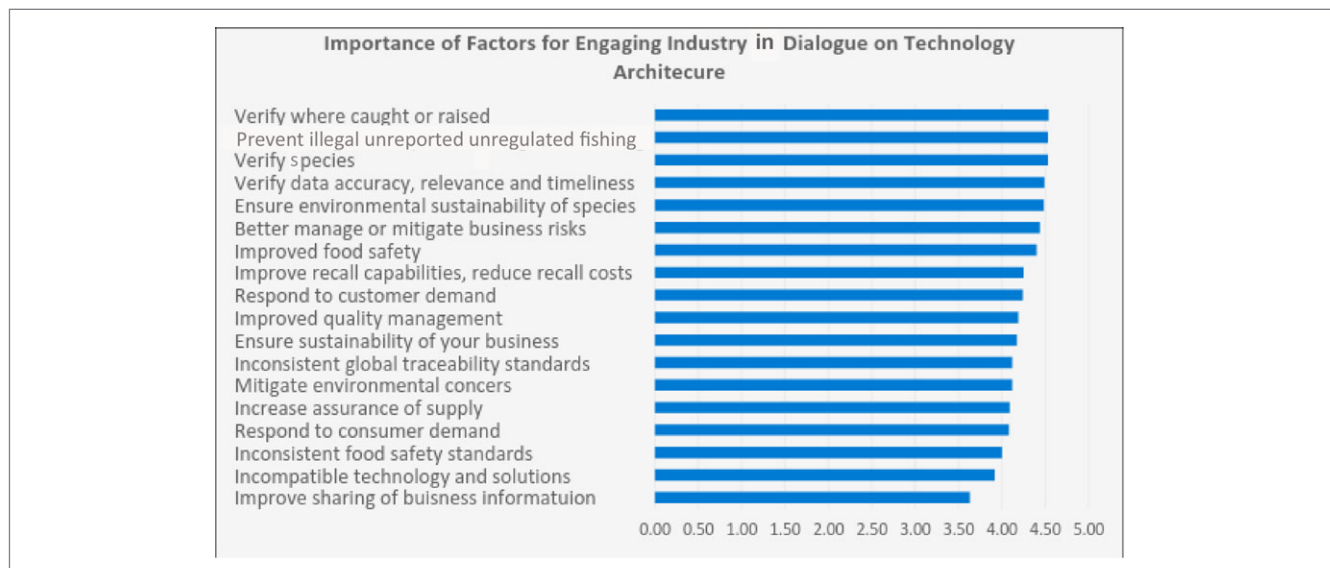

Figure 6–Topics that will engage industry in dialogue.

dollars. This suggests that a 3-tiered approach may be effective in engaging the largest stakeholder group possible.

The first tier would be to engage directly with the largest companies (those with annual revenue of $1+ billion) and others through their respective buying groups and local, regional, national, and international trade organizations. Larger companies are more likely to engage in efforts to improve the tracing of products and implement traceability from strategic (rather than only operational) perspectives. Publicly held companies are considered more likely to engage in interoperable traceability efforts because of the nature of their mandated reporting to customers and suppliers. As has occurred in other industries, companies that directly interact with the public (that is, restaurant chains and supermarket chains) are likely to be the most motivated to drive change, given the scrutiny that they receive from the end consumer.

The second tier would be dialoging with each segment of the industry listed above by engaging with the trade associations that support them. Globally, organizations such as the Food Marketing Institute (FMI), British Retail Consortium for Global Standards (BRC), and German Retail Federation (HDE) in Germany, and others represent the retailer community. Conversely, there are many that represent restaurants, such as the National Restaurant Association in the United States. Seafood-specific organizations such as the National Fisheries Institute (NFI) in the United States should be a first point of contact. NFI has already been a leader in implementing traceability, beginning with release of its "Traceability for Seafood, U.S. Implementation Guide" in March 2011 in cooperation with GS1 U.S. NFI has continued its traceability work with pilot testing of the Guide to gauge its efficacy and is currently assessing how to use GS1 global standards and IT tools

Fragmented Value Chain: Transactional trading comprising a series of short-term, unique interactions. Because information is withheld, price, volume, and quality are the only factors used in decisions. Accordingly, relationships are more adversarial and distrusting; and without the ability to pool intercompany knowledge and other resources, the chain struggles to adapt to changing market demands and new technology.

Cooperative Value Chain: Businesses pursue medium-term operational support. The extent to which this evolves into strategic coordination will depend upon the compatibility of the culture of different businesses, as well as external environmental business factors.

Coordinated Value Chain: Businesses share complementary objectives, attitudes, and leadership styles, and the benefits of mutual commitment to each other are recognized. This leads to at least some businesses adopting strategically aligned structures and perspectives.

Collaborative Value Chain: Long-term strategic alignment exists, based on sharing resources and/or developing capabilities which deliver mutual benefits. This requires transparency and businesses to possess compatible cultures, vision, and leadership, creating conditions for investment in relationship-specific products, services and assets. While significant rewards can result, there are also risks associated with this interdependence.

Figure 7–Four classifications of chains (Sterling and others 2015).

such as EDI to trace sustainability information through the supply chain.

Finally, "champions" who will be the voices of the industry are essential for success. There are several thought leaders and key influencers who have been engaged in discussions around interoperable traceability, ensuring that they fully understand and are engaged with GFTC in this project is very important. However, as there is the danger of polarization occurring given the complexities and differing agendas that typify the seafood industry, the Engagement and Communications TAG recommends establishing a solid base of awareness before bringing together thought leaders. Beyond conferences, seminars, forums, and workshops, mechanisms that could be used to engage with the broader industry include:

- press engagement;
- website with easily understood models and infographics, including video footage; and

- materials designed for consumers that cite the benefits that will be created as the infrastructure develops.

Engaging stakeholder groups more widely. Successfully developing and implementing a technology architecture required to enable effective interoperable seafood traceability will rely not just on bringing the necessary commercial businesses to the table, but will rely on finding commonalities between groups that serve widely varying constituencies. Industry stakeholders must also be engaged more broadly and integrated into the project. The value of engaging industry stakeholders more widely, with 2 types of stakeholder groups as specific examples, is discussed below.

NGOs. As traceability continues to gain importance within the seafood industry, NGOs that work on sustainable seafood issues have been engaging in traceability discussions by participating in multi-stakeholder initiatives, collaborating with other NGOs to harmonize efforts, and advancing traceability improvements via
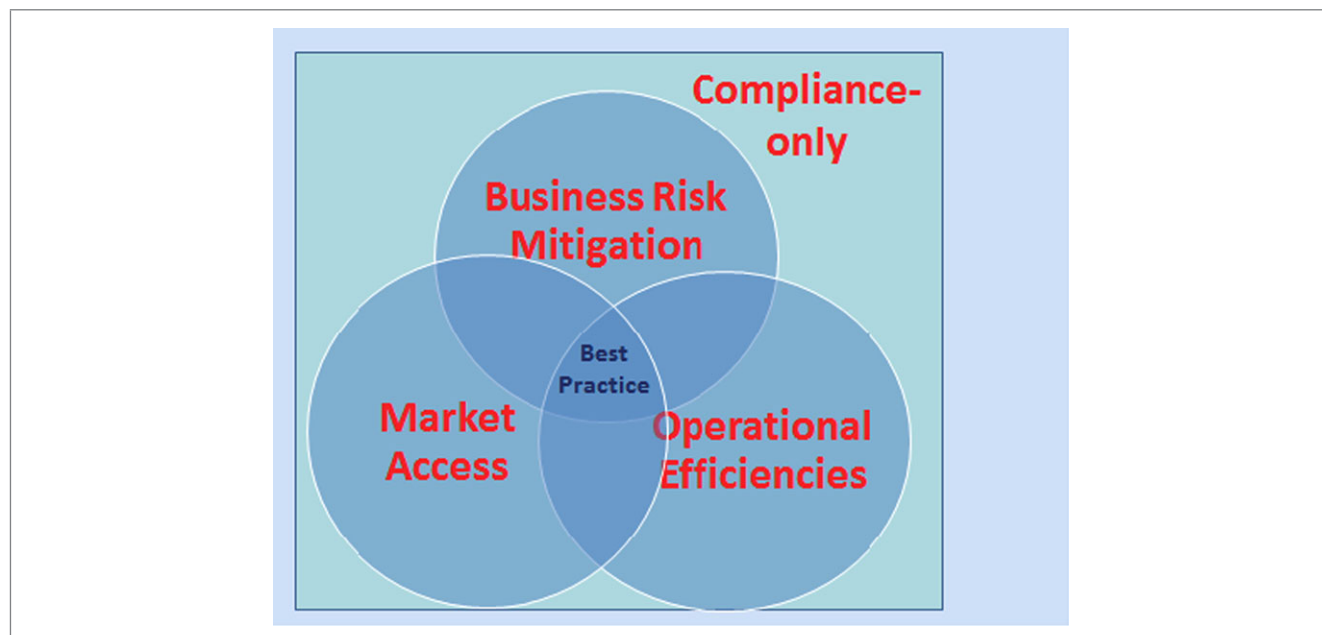
Figure 8–The objectives of traceability system investments (Sterling and others 2015).

NGO-industry partnerships. Levels of NGO engagement in traceability discussions and projects vary from one organization to the next, with some organizations taking on a more prominent role than others. Seafood traceability has historically been used to address food safety concerns, but it has developed over recent years as a tool to evaluate sustainability of products, share information with fisheries managers, and ensure that products are not from illegal fisheries or produced with illegal labor. As traceability has evolved in its application, NGOs have developed expertise in applying traceability to critical environmental and social issues within seafood supply chains.

A large source of NGO engagement in traceability discussions occurs through NGO partnerships with companies and seafood businesses. Out of the top 38 North American and European retailers, those representing 84% of sales have some level of commitment to sustainable seafood, either through NGO partnerships (71%) or the Marine Stewardship Council, a chain of custody and sustainability certifiers (13%) (California Environmental Associates 2015). In addition to the retail sector, NGO partnerships with other segments of the supply chain have become more common, because distributors and producers have evolved to meet retailers' increasing demand for sustainable products. As companies have progressed with meeting their sustainability commitments, traceability has evolved to become a common topic of conversation both within the NGO community and between NGOs and each of their business partners.

In addition to their partnerships, NGOs are actively involved in and are contributing to broader, multi-stakeholder traceability discussions. Many North American NGOs that work in the seafood realm are participating in the public comment rounds of the Presidential Task Force on Combatting IUU Fishing and Seafood Fraud, in which establishing a national seafood traceability framework is a key objective. Other significant traceability discussions such as GFTC's Seafood Traceability Architecture Project and World Wildlife Fund's (WWF) Global Seafood Traceability Dialogue include consultation and input from diverse stakeholders, including many organizations from within the NGO community.

NGOs in both North America and Europe have also published reports on various aspects of seafood traceability, including traceability best practices and guidelines, information technology, and current industry efforts.

Meetings and workshops during popular seafood events are an effective means of engaging NGOs, not least because it reduces the financial and logistical constraints that many NGOs face when attending additional meetings. Webinars are expected to provide another effective and efficient means for engaging NGO stakeholders in a dialogue on developing a common technology architecture.

Technology solutions providers. An important stakeholder in the success of getting widespread adoption of the newly created Seafood Traceability Initiative technology standard is the software development industry. Engaging the software industry in the requirements of the initiative will make it easier for developers to quickly gain an understanding of the requirements, so they can adapt or build programs aimed at the seafood industry. The Communication and Engagement TAG hopes this will lead to more options being available for seafood stakeholders by creating a competitive marketplace of options from which seafood companies can select the right technology for their size and type of company. By ensuring there are software options ready for implementation, seafood companies that need such options will find it easier to adopt the standard and communicate the required information to the next partner in the chain.

The Engagement and Communications TAG recommends that a website landing page devoted to solution providers be created on the Seafood Traceability Initiative website. This solution provider page should include a written summary of the industry requirements and technical specifications offered in multiple languages as well as video-based communications including one or more recorded on-demand webinars. Technical documents should outline what information the different sectors of the seafood industry must maintain (harvesters, processors, distributors, and so on) to satisfy the initiative guidelines and any standard formats for barcode labels, EDI files, and human readable content (labels and/or

documents) that each company should record and make available to the next level in the supply chain.

As well, a communication portal such as LinkedIn and IFT Connect could be used to facilitate open dialogue between solution providers and other industry stakeholders.

Recommendations

The following section presents summarized recommendations for designing a seafood traceability architecture that can meet the needs of the global seafood industry. Each of the 8 processes contained in Table 6 are critical technical components of an information system. Associated with each process are 2 or 3 core practices that work in tandem to meet the architectural objectives. Many of these practices have been developed by industries that are recognized as world leaders in developing comprehensive traceability systems. Although the recommendations arising from this analysis are preliminary, they provide a starting place to conduct more in–depth study and development of practices that are comprehensive, congruent, flexible, and adaptable to meet the traceability needs of a diverse and dynamic seafood global industry. Table 6 is followed by a more detailed consideration of 3 factors that are critical to enabling global interoperable traceability: (1) standards, (2) CTE/KDEs, and (3) data Accessibility.

Standardized unique identifiers

Unique identification numbers offered in systems such as GS1 Standards must be fully explored as a necessary prerequisite to traceability and therefore interoperability. Business systems such as SAP are already used in traceability and can be modified to enable interoperability. Some value chain stakeholders, for example smaller importers, may require some convincing regarding the need for unique identifiers. What is more difficult is applying unique markers at the point of harvest, especially for those species with unusual harvesting procedures (for example, blue swimming crab), species that are harvested using different gear types, and when co-mingling of species and lots. This is where Fishery Improvement Plans manage initial flow in the supply chains but are a limitation to full pedigree. A neutral, GFTC–led forum for discussion of identification requirements would be valuable to the goal of interoperability and eventually validation of the process through pilot testing.

Standardized CTE/KDEs

The research identified numerous CTEs and KDEs in the realm of seafood traceability. CTEs are not as critical as the name implies because it is the KDEs that carry the identifying information across nodes and transition points. If traceability purports to prevent illegal fishing practices or seafood fraud, all data entered must be true and correct. As with seafood HACCP, a mechanism for validation and verification of data must be implemented. Sharing erroneous data is detrimental to commercial practice. A pilot study is suggested to validate how information is provided via the design of the traceability system. A random traceback exercise is suggested to verify whether those charged with data entry are doing the task correctly and completely. It is critically important to identify efficient mechanisms that can be put in place within the architecture to authenticate data, as it will increase industry stakeholders' confidence in the quality and authenticity of data gathered, managed, and shared along the supply chain.

Data accessibility

Interoperable traceability requires a global perspective because seafood is traded globally. Seafood imports are rising (NOAA 2015), and it is estimated that over 90% of seafood sold in the U.S. comes from off-shore sources. Global considerations and interests create a complicated web of data security factors that must be managed for a system to be effective. For governments and government agencies, KDEs are often the sources for the data they seek. Groups such as the Food and Agriculture Organization of the United Nations and the International Maritime Organization of the United Nations are keepers of global registry data. A variety of private and public groups will seek data for individual and pan–industry purposes. Enabling these demands to be met on an ongoing basis without compromising commercial interests can only be achieved by establishing an effective impartial governance process that determines, and then oversees, the accessibility of individual stakeholders to the data.

Authors' Contributions

IFT thanks the authors of this brief for all the input, time, and expertise they contributed during the writing of this Issues Brief.

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Table 6–Recommended practices in designing and managing a global seafood traceability architecture.

Process	Recommended global seafood architectural practices
Product identification	Human- and machine-readable codes on each product that represent at least a unique global identifier. The unique global identifier is composed of a global identification number that identifies the product type and a lot number that identifies data at a finer scale (for example, dates, vessel, production facility, etc.) The original harvest lot number should be identified and linked to all other "lot" or "process/batch" numbers generated during supply chain activities.
Data addition	All data generated by each node in the supply chain are linked to the unique global identifier. When a new lot number is assigned, previous lot numbers are linked to it. All KDEs are linked to the unique identifier.
Data partition	Firm-level partitioning or "data-siloing" is minimized to provide access to product data via the architectural portals (conditional on proper "permissions" and high-level security). Clear definitions of data requirements are needed.
Data storage	All or most data should be stored at the level of the individual firm. Some "core" traceability data could be stored at the "architectural cloud" level if efficient and secure.
Data transmission	Data are transmitted electronically (via data portals) with required permissions. Unique identifiers transmitted with both the data and the product. Data can be transmitted using predesigned modules and/or menus that best meet the strategic needs of individual firms and supply chains.
Data security and access	Architectural framework must be secure to protect privacy and intellectual property of individual companies. Access is granted by each firm via "permissions" to users of data. Different classes of data may have different permission requirements.
Data collection and measurement	Industry must define KDE's and standardize measurement. Data collection is by individual firms using a variety of techniques (such as paper, electronic sensors, scanners) An interface where manually recorded data can be converted to electronic form for transmission is needed.
Data validation	Architecture may identify key missing data in transmission process. Architecture can also transmit 3rd party authenticators for firm-level data or other firm-level validation information.

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Conflicts of Interest

None of the authors have any conflict of interest to declare.

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Appendix 1: Full Practices and Processes Case Studies

Automotive Industry Case Study

The global automotive industry is dominated by large corporations based in the U.S., China, Japan, South Korea, and Europe. Many of these corporations operate on a global scale, with subsidiaries, business units, and divisions operating world-wide. The industry is highly profitable (profits were approximately $60 billion in 2012), but profits are highly dependent on world-wide economic conditions (Advanced Industries 2013). The industry is in a perpetual state of change, with rapidly changing consumer expectations (which are highly dependent on safety and quality perceptions), high levels of competition in and between globally-linked economies, and the emergence of new markets (China accounted for $18 billion in profits in 2012 (Advanced Industries 2013) all significant drivers of firm behavior (Cognex 2011).

The current trend in the automotive industry is toward out-sourcing production of individual components to firms located all over the world. Given the large number of components that make up a vehicle, this has resulted in extremely complex and dynamic supply chains, and to information on components and sub-components being distributed across a large number of firms (Murthy and others 2008). Automobile firms therefore demand and require information sharing as a prerequisite to conducting business.

An important characteristic of the automobile industry is the sheer complexity of the production process. A single vehicle is generally made up of thousands of components potentially sourced from hundreds of different companies around the world (AMS 2014). The need for effective global traceability in this industry is clear. Apart from fighting increasingly rampant counterfeiting of replacement parts (worth almost $12 billion in 2013 [AMS 2014]), adhering to strict recycling regulations in countries such as Japan (Murthy and others 2008), and the business efficiencies gained from effective traceability (IBS 2012), the main driver of traceability corresponds to adhering to mandatory safety recalls of defective parts (Cognex 2011). The financial cost of safety recalls in the automobile industry is significant and grows exponentially as that part becomes part of a sub-assembly, and then a part of a consumer-driven vehicle. For example, recalling a bad part at the supplier plant where it originates can cost between $25,000 and $500,000, up to $1 million at the assembly plant, and more than $10 million if that part makes it into an automobile that is being driven (Cognex 2011). Without effective traceability, vehicle manufacturers may struggle to conduct a timely recall, as well as pass on recall costs to the source of the defective part (LNS Research 2011). In the U.S., the National Highway Traffic Safety Administration (NHTSA), through the Transportation Recall Enhancement and Accountability, and Documentation (TREAD) Act of 2000, has authority to administer safety recalls and oversee the adequacy of automobile manufacturers' recall campaigns (LNS Research 2011).

Traceability in the automotive industry documents the genealogy of the components and sub-components of automobiles and is a complex process (Cognex 2011). Not only are there thousands of components per vehicle that potentially need to be traced, these components are produced by a wide range of firms situated in a wide range of countries around the world. The major current trend in traceability in the automotive industry centers on the idea of being able to trace each component of an automobile to its source, and throughout the entire life cycle of the vehicle (Cognex 2011). Firms in the industry generally maintain sophisticated Enterprise Resource and Planning (ERP) systems, and they use these systems to link subcomponents to components, sub-assemblies, assemblies, and finally to the completed automobile. Enterprise Quality Management Software (EQMS) packages are increasingly employed to facilitate the integration of a firm's ERP with its business processes (IBS 2012). This type of software facilitates quality management across a firm's complex operations and allows disjointed modules of an overall ERP system to communicate effectively (LNS Research 2012).

The physical component of an advanced traceability system in the automotive industry increasingly takes the form of Direct Part Marking (DPM). Every component of an automobile is given a unique identification that is affixed to the part in a range of ways. These methods differ depending on the material, requirements for readability, and requirements for durability. For example, ink jet printers may print codes on plastic parts while metallic parts are laser-etched with codes. Codes are generally machine-readable, and while 1D barcodes are commonly used there is an increase in the use of 2D codes which have the advantage of being able to store a significant amount of data and are readable even when damaged (Freedom Corp 2007). To avoid production errors, many manufacturers produce build sheets for a sub-assembly containing the required component identifications. Operators then scan each part in the assembly process to ensure that the correct part is being used. This process reduces product mislabeling, which was identified as the number one cause of quality-related issues in the automotive industry (Freedom Corp 2007).

Overall, traceability in the automotive industry has evolved as a regulatory necessity as well as a way to improve business efficiency. The stakes are high in the automotive industry when it comes to traceability. The high costs of recalls (which includes damage to consumer opinions) and the regulatory threat of the NHTSA means that automobile manufacturers demand ever-increasing standards of quality, as well as the ability to trace every component of a vehicle back to its sources and throughout the lifecycle of the vehicle. The widespread use of advanced ERP and EQMS systems has driven the use of machine-readable product identifiers that are increasingly being applied to more and more parts of an automobile. Methods both for affixing identifiers to components and for machine-reading identifiers make up the physical component of advanced traceability systems, and they are perhaps as advanced as in any other industry in this regard.

Pharmaceuticals Industry Case Study

The global pharmaceuticals industry deals with thousands of different products and is extremely high-value, generating over $300 billion in revenue annually (WHO 2015). Although demand for pharmaceuticals of all types is global, the supply side of the industry is relatively consolidated. The 10 largest firms, which account for over 30% of the global market, are all based in North America and Europe (WHO 2015). The industry is also highly regulated, with more than 50 countries having enacted pharmaceutical product serialization laws, and various government agencies (such as the Food and Drug Administration (FDA) in the U.S.) given authority to regulate the industry (CSC 2015).

The main driver of traceability in the pharmaceuticals industry is government regulation, ostensibly designed to protect patient safety. Drug counterfeiting poses a significant health risk and is rampant in the industry. It is believed that between 7% and 15% of all medicines globally are counterfeit. With that number rising to an incredible 40% in South America and almost 70% in West Africa (National Fisheries Institute 2011). While an increasing number of governments are taking tracing and serialization regulation in the pharmaceutical industry seriously, laws that are enacted differ significantly among countries, creating obstacles for the global supply chain. Some laws also require independent, and often competing, organizations to work together and share information to ensure life cycle traceability, which is an added barrier to implementation (Murthy and Robson 2008). In addition, the fact that pharmaceuticals are often part of extremely long and complex supply chains (being bought, stored, and resold several times before making it to the point of sale) intensifies the difficulties faced in implementing traceability in this global market, especially in the absence of global standards (Pharma IQ 2014).

There are several emerging models for traceability in the pharmaceutical industry, the choice of which depends on market-specific and country-specific characteristics (GS1 2010a):

The 'one-up, one-down' model is perhaps the most basic traceability model and is similar to the requirements in place for ensuring traceability for food products in the U.S. and the EU. In this model each firm in the supply chain keeps a record containing the product identifiers and characteristics, from where the product was received, and to whom it was sent to. Although it is possible for the product to be traced throughout the entire supply chain using this model, the fact that there is no single repository for tracing information means that the speed at which products may be traced is often not as fast as in other models (Murthy and Robson 2008).

The "pedigree" model for traceability requires that a record containing information on product identification, characteristics, and any change of ownership accompanies the product (either physically or electronically) throughout the supply chain. For example, the California e-Pedigree Law, which comes into effect in 2015, requires an electronic pedigree to accompany all prescription drug distributions in California starting from the manufacturer until the point of sale. A pedigree in this case is an electronic record of all transactions that result in a change of ownership, and the law requires that these records be maintained using an interoperable, electronic system that ensures compatibility at all stages of the supply chain (GS1 2012a).

The "point of dispense authentication" model is a process that determines whether a product is actually what it purports to be at the point of sale. For example, Turkish law requires drug manufacturers to uniquely identify their products using Global Trade Identification Numbers (GTINs) and lot/batch numbers, and to upload a list of these numbers to a central government database. The drugs are then authenticated at the point of sale by checking human- and machine-readable identifications on product packaging against the central database (Axway 2011).

The "distributed network track and trace" model requires that all firms who produce, buy, sell, store, or otherwise impact a product in the supply chain publish key data that are accessible to other authorized parties in the supply chain as well as government regulators (GS1 2010a). Information is published to a 'cloud' and permissions are granted by the owners of the data as to who is allowed to access it. This model is perhaps the most advanced traceability architecture but may also be the most complex to implement.

In all of these traceability models, the common denominator is a unique identification that is affixed to each package of drugs. The most common method of identifying products is by using either a 1D barcode or a 2D data matrix code, with the latter capable of storing a significant amount of product information. Radio frequency identification (RFID) is also growing in acceptance in the industry, although there are significant cost and technology barriers to implementation (Criswell 2012). Although 1D and 2D codes require a direct line of sight to the product, as well as relative proximity, RFIDs have a larger range for identifying product and a higher read accuracy rate (Barchetti and others 2010; Criswell 2012).

A system that is widely used in the pharmaceutical industry is the electronic product code information services (EPCIS) system, represented mainly by the GS1 organization (GS1 2013). The EPCIS is a global service that contains information, provided by the manufacturer, on every product in the industry. Based on the use of this service, GS1 proposes the use of the electronic product code (EPC) global network architecture which is effectively a set of standards for unique product identification, hardware devices, software, network services, and data interfaces in the healthcare industry (Barchetti and others 2010). This architecture was designed to create a universal, yet distributed, database that can be queried to obtain any information required, with the necessary permissions, and is similar to the "distributed network track and trace" model for traceability. Given that the most fundamental concern for effective global traceability in the healthcare industry is the use of a unique product identification, the use of a single organization to assign and record that identification reduces complexity.

The pharmaceutical industry is currently undergoing rapid change pertaining to traceability. Traceability in this industry is perhaps at least as important as in any other industry given the high risk to both public health and company profits through counterfeiting medicines. In response the industry is exploring global solutions, mainly shepherded through the GS1 organization, and the use of their unique product identification systems. However, implementing global traceability in this industry is extremely challenging given the disparity in regulations between countries, the complexity of the supply chain, changing market structure (there has been significant growth in internet sales of pharmaceuticals), and the sheer number of drugs involved. Given that drug manufacturers supply drugs to many different countries globally, these issues are set to intensify as more and more countries implement serialization and traceability laws for pharmaceuticals.

Fresh Produce Industry Case Study—Traceability Processes and Practices

The fresh fruit and vegetable industry is increasingly globalized, supplies a wide range of products, and is high-value, generating approximately $2 trillion in revenue annually (First Research 2015). In the U.S., the industry is fragmented. The 50 largest wholesale firms only account for approximately 30% of total revenue, which for the entire industry was estimated at $122.1 billion in 2010 (Cook 2011; First Research 2015). Many types of suppliers, distributors, wholesalers, shippers, and importers, serve food service operators and food retailers, and industry-wide generalizations are difficult as company characteristics tend to vary by the product or product group each one supplies (Cook 2011). Two major current trends in the industry are the growth of sales directly from farm to consumer, and growing imports of fresh produce from developing countries. In 2010, imports of fresh produce into the U.S. were valued at $12.3 billion (Cook 2011).

All fresh produce shares 2 characteristics: perishability (which limits storability) and seasonality (which creates supply challenges; Cook 2011). Coupled with increasing consumer demand for year-round, high-quality fresh produce and the introduction of mandatory food safety traceability requirements (such as the U.S. Food Safety Modernization Act of 2010), the challenges of implementing global traceability for the industry are significant. In response several major industry groups in North America have created the Produce Traceability Initiative (PTI) in 2006, an industry group mandated with improving current produce trace-back procedures while developing a globally standardized, electronic-based industry traceability system (Produce Traceability Initiative 2011).

Since the introduction of the U.S. Bioterrorism Act of 2002 which requires each handler of food products to keep records documenting the movements of its products one-step forward and one-step back in the supply chain, most firms in the industry possess an *internal* traceability system. The PTI aims to establish *external* traceability in the industry by building on firms' internal traceability systems in 2 ways: (1) establishing a common nomenclature for product identification, as well as a common numerical identification system for each product (the global trade item number, GTIN), and (2) requiring that each firm tracks 2 common pieces of information (the GTIN and the lot number) as each case of produce moves through the supply chain. This system is facilitated by the fact that every firm in the supply chain handles a standardized unit of product—the shipping "case"—which is the level at which traceability currently occurs (Produce Traceability Initiative 2011).

Global traceability in the fresh produce industry therefore requires a case-coding solution which is generally a label affixed to each case in human- and machine-readable form. The label contains at least 2 pieces of information: the GTIN which identifies the owner of the brand as well as the type of product in standardized nomenclature, and the lot number which specifies the production lot from where the product originated. Other information required by retailers or government regulation, such as country of origin, may be printed on the same label. PTI publishes several best practices guides for traceability, including those for label formatting (GS1 2010b). This system allows each firm in the supply chain to scan each case and retain the encoded information in its computer systems. Although there is no central database that holds information for the entire supply chain, firms search their own internal traceability systems to retrieve information on where the case originated, and to whom it was shipped (the "one-step forward, one-step back" protocol; Produce Traceability Initiative

2011). The electronic format and supply chain standardization of this information makes information retrieval relatively fast.

The growing adoption of information technology systems such as Enterprise Resource Planning (ERP) systems, and advances in tracking technology such as mobile scanners/readers and voice-picking systems, has helped to streamline internal traceability, and the costs of implementing these systems have decreased significantly in recent years (Cook 2011). The standardized format of products in this industry (the "case") means that the essential tools for identifying products are common to the entire supply chain.

Major drivers of traceability in the fresh produce industry include food safety concerns and labor issues. Although fresh produce enjoys a safe and wholesome image, fresh produce is often consumed raw—there is no pathogen "kill-step." Industry recognizes that maintaining the "safe" image of fresh produce is essential to profitability. Labor concerns are also important. It is estimated that the industry relies on undocumented workers for most of its labor supply. There is a widespread recognition that governments are starting to regulate and enforce labor conditions much more actively, increasing the importance of effective traceability in the fresh produce industry (Cook 2011).

Verification of data and company practices in the industry is generally conducted by third-party auditors, with the costs borne by industry. There is significant redundancy in this system as data verification is often duplicated, and there are calls to standardize verification procedures (Cook 2011).

The industry has identified the lack of information-sharing as a significant barrier to realizing value from traceability. Although some firms freely share data, especially those that are members of grower cooperatives, information-sharing is still rare, and the fact that consumer needs are constantly changing means that the need for greater vertical coordination in the supply chain is apparent (Cook 2011). Another benefit that could be realized from the implementation of a global traceability system is reducing product loss, which is estimated to be on the order of 10% of the total value of the supply chain (Cook 2011).

Traceability in the fresh produce industry has improved greatly since the formation of the industry-funded PTI in response to concern about stringent food safety regulations and changing consumer demand. While the fresh produce industry shares many of the same characteristics as the seafood industry (size, fragmentation, large number of products, global supply chain), the standardization of a traceable unit (the "case"), has greatly simplified the implementation of an interoperable traceability system in this industry.