Through a Glass Clearly: Standards, Architecture, and Process Transparency in Global Supply Chains

CHARLES STEINFIELD, M. LYNNE MARKUS, AND
ROLF T. WIGAND

Charles Steinfield is a professor and chair in the Department of Telecommunication, Information Studies, and Media at Michigan State University, where he has received both Teacher-Scholar and Distinguished Faculty awards. His research has focused on organizational and social effects of information and communication technologies (ICT), including studies of computer-mediated communication in organizations, electronic commerce effects on buyers and sellers, intermediation in electronic markets, social capital implications of ICT use, and industry-wide information systems standards development and adoption. He has received numerous federal, foundation, and private industry grants and is the author or editor of 6 books and over 100 articles.

M. Lynne Markus is the John W. Poduska Sr. Professor of Information and Process Management at Bentley University. Professor Markus's teaching, research, and consulting interests include enterprise and interenterprise systems and IT-enabled organization change. She is the author or editor of 5 books and over 100 articles. Her research has been supported by numerous government and industry grants. Her article (co-authored with Charles Steinfield, Rolf T. Wigand, and Gabe Minton), titled "Industry-Wide IS Standardization as Collective Action: The Case of the U.S. Residential Mortgage Industry," won three best paper awards. She was named Fellow of the Association for Information Systems in 2004 and received the AIS LEO Award for Exceptional Lifetime Achievement in Information Systems in 2008.

Rolf T. Wigand is the Maulden-Entergy Chair and Distinguished Professor of Information Science and Management at the University of Arkansas at Little Rock. His research interests lie at the intersection of information and communication business issues, the role of newer information technologies and their effect on organizations and society, as well as their strategic alignment within business and industry. Most recent and current National Science Foundation (NSF)–funded research has focused on the global impact of electronic commerce in ten nations, the impact of electronic commerce on the real estate industry, as well as the software standards development in the mortgage, retail, and automotive parts supply industries, and trust, leadership and strategy in virtual environments (NSF Virtual Organizations as Sociotechnical Systems [VOSS] Program). Dr. Wigand also participated in and was a consultant to the Information Technology for Adoption and Intelligent Design for E-Government (ITAIDE) project funded by the European Commission from 2006 to 2010. He is the author of 6 books and over 130 articles, book chapters, and monographs.

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ABSTRACT: Despite evidence that a lack of interoperable information systems results in enormous costs, development, implementation, and effective use of interorganizational systems (IOS) remain an elusive goal for many companies. Lack of interoperability across systems is especially problematic for manufacturers dependent on global supply chains. We develop propositions about the characteristics of IOS that affect information transparency in supply chains. Specifically, we propose that data and process standards are necessary, but not sufficient, to solve such information transparency problems. Instead, standards need to be complemented by hub-type information technology architectures that are shared by organizations participating in an industrial field, not just by the participants in one manufacturer's supply chain. These arguments are supported by an automotive industry case study involving data and process standardization and a shared, cloud-based architecture. We conclude with additional aspects of the case that may be relevant to addressing information transparency problems in global supply chains.

KEY WORDS AND PHRASES: automotive industry, case study, data standards, EDI, industry study, information transparency, interorganizational systems, software as a service, supply chain.

THE LITERATURE ON SUPPLY CHAINS IS REPLETE WITH DISCUSSIONS of information-related coordination problems. The best-known example is the "bullwhip effect," in which small errors in demand forecasts propagate through various tiers in a supply chain, resulting in costly inventory build-ups, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules [44]. A well-known example occurred at Cisco Systems when overlapping orders in the company's vaunted global supply chain led to considerable excess inventory in a period of slumping demand [19].

Even where demand forecasts are not involved, substantial supply chain coordination problems can arise simply from data rekeying errors that occur as information is passed from one organization to the next in the chain. For example, a 2004 U.S. National Institute of Standards and Technology (NIST) report documented huge opportunity costs associated with inadequate interorganizational systems (IOS) in the automotive and electronics industries: "We estimate the total annual costs of inadequacies in supply chain infrastructures to be in excess of $5 billion for the automotive industry, and almost $3.9 billion for the electronics industry. These figures represent about 1.2% of the value of shipments in each industry" [70, p. ES-1].

A variety of information technology (IT)–enabled process innovations have been proposed to address information-related supply chain coordination problems, including electronic data interchange (EDI) [53], IOS [2, 20, 21], electronic marketplaces and coordination hubs [17, 63], and XML (Extensible Markup Language) data and process standards [7, 49]. Despite their many documented benefits, these IT solutions have failed to eliminate information transparency problems in global supply chains because of low adoption, particularly among smaller enterprises and among the more remote or peripheral members of supply chains (e.g., transportation companies and customs agencies). Low adoption may in turn be traceable to technical design characteristics with implications for adopters' costs, benefits, and knowledge burdens.

The goal of this paper is to extend the literature on supply chain coordination and IOS adoption and benefits by developing a set of theoretical propositions about the characteristics of IOS that are likely to promote or inhibit IOS adoption and information transparency in global supply chains. We focus on two specific characteristics of IOS in this context: (1) whether they are proprietary or standards based, and (2) whether information flows sequentially in a point-to-point fashion among supply chain partners or is provided simultaneously to relevant partners via a coordination hub. We advance theory by proposing that *the combination of* industry-wide data and process standards *and* a shared IT coordination hub (one that is accessible widely in the industry, not just to the members of particular supply chains) is necessary for widespread adoption and improved information transparency when separate supply chains are interconnected with numerous nonexclusive relationships among members of an industrial community.

Our analysis is supported by an in-depth case study of an automotive manufacturer's efforts to implement an IOS in its global supply chain. We show that this manufacturer's past efforts did not succeed because they lacked the combination of standards and a shared IT architecture, whereas a more recent approach, involving collective industry development of standards and a cloud-based coordination hub, is exhibiting signs of success. Our case analysis is augmented with brief examples drawn from other research studies. We conclude our paper with a discussion of other aspects of our case study that may be relevant to addressing information-related supply chain problems and that merit future research. Ultimately, our case study and conceptual contributions highlight a new approach to IOS implementation that has important implications for information systems (IS) theorists as well as management executives.

Theoretical Background

The ability of organizations to benefit from using IOS is well known and has been widely studied [2, 16, 27, 38, 43, 58, 59]. Much of this prior work, while examining diverse typologies for IOS structure that speak to cooperative versus competitive relationships among trading partners (e.g., Choudhury's [16] distinction between electronic dyads, electronic monopolies, and multilateral IOS), are mainly concerned with information flows and transactions between a buyer and a seller, rather than addressing the kinds of information transparency requirements found in a complex supply chain. Although much of the research has focused on dyadic relationships between buyers and suppliers, attention has recently turned toward more complex "business networks," involving collections of organizations that collaborate in some way [41, 65, 66].

One common type of complex business network is the extended (multitier) supply chain; particularly significant are extended supply chains that cross national boundaries. An example is the automotive supply chain, in which U.S. original equipment manufacturers (OEMs) source parts from overseas suppliers, which in turn often source parts from other suppliers. In addition to the main players in such supplier chains, there are often numerous peripheral actors that nevertheless play essential supporting roles. Among these supporting actors are transportation providers (ocean, rail, and truck carriers), warehouse operators, customs officials, and third- and fourth-party logistics providers (3PLs and 4PLs) that provide “one-stop” outsourced services for companies that choose not to manage logistics for themselves. (Note that all our arguments apply equally to distribution chains, but for simplicity we refer to supply chains throughout.)

An important characteristic of extended supply chains is that they are often interconnected. In some industries, such as grocery manufacturing and apparel retailing, “dedicated” supply chains, in which “captive” suppliers have exclusive relationships with particular customers, are common. However, in many other industries, such as the automotive industry, suppliers tend to work for many customers, sometimes for companies that are direct competitors and sometimes for customers in different industries (e.g., automotive, aerospace, marine, and power generation). As discussed below, the degree of interconnection in supply chains has important implications for transparency problems and for the adoption of technology that is intended to address information transparency problems.

Extended Supply Chains and Their Information Problems

Historically, information about goods moving through supply chains was transported physically along with the goods themselves, in the form of documents that accompanied shipments. Improvements in information and communication technology enabled organizations to send information separately from, and in advance of, shipments, allowing for various kinds of preplanning and adjustments. Over time, more advanced ITs tended to replace less advanced ones. EDI has been used since the 1980s in preference to mail, telephone, e-mail, and facsimile for high-frequency transactions by large, technology-savvy organizations. Although EDI achieved a relatively low level of penetration until well into the 1990s [61], the widespread availability of Internet-based technologies (e.g., portals, extranets, and Web EDI) had undoubtedly increased the use of computer-based forms of interorganizational coordination.

At the same time, the information transparency problems of extended supply chains remain severe. One class of problems relates to the lack of seamless integration all the way through the supply chain. OEMs and their first-tier suppliers may use EDI, but suppliers from more distant tiers and supporting actors may rely on other forms of communication (e.g., fax). As information is passed sequentially from point to point, information must be rekeyed, often several times, introducing delays and the potential for errors. For example, in a survey commissioned by the Automotive Industry Action Group (AIAG; www.aiag.org) in 2005, 79 percent of respondents reported rekeying data multiple times, and 91 percent reporting problems found resulting from the use of phone, e-mail, and fax.

Errors and delays may be compounded by the lack of data and process standards across supply chain members. Business practices vary from industry to industry. Therefore, when supply chains are interconnected, there is the possibility for errors from misunderstandings about appropriate business practices or the meaning of business terms in differing business contexts.

Perhaps the most pernicious information problem in extended supply chains is the "bullwhip effect" [44], which results from lack of *visibility* or transparency in supply chain coordination. Visibility has been defined in various ways in the supply chain literature, but generally refers to the status of orders, inventory, and shipments across the supply chain [9]. More precisely, Francis defines supply chain visibility as "the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events" [25, p. 182]. Bullwhip effects refer to the situation where small errors in forecasts of demand among supply chain participants can sometimes be propagated back through the supply chain, leading to large build-ups of inventory that may ultimately generate huge losses for a buyer company [44]. Because of long lead times in the delivery of parts, companies must forecast future demand and communicate these forecasts to their suppliers, which in turn must make forecasts for their suppliers. In 2001, Cisco had a $2 billion write-down stemming from such forecasting errors, which occurred despite Cisco's investment in an advanced information-processing hub to connect the company with suppliers from at least two supply chain tiers [19].

Altogether, information transparency problems in extended supply chains can add up to major costs. Two detailed studies conducted by NIST researchers identified the costs arising from lack of adequate interoperability in data exchanges in the automotive supply chain. NIST researchers initially estimated that the lack of such interoperability resulted in $1.05 billion in annual costs in the U.S. automotive sector [11]. A later NIST study [70] found that the U.S. automotive sector wasted more than $5 billion annually due to shipment delays, order cancellations, and forecast revisions. Continued reliance on the use of telephones, faxes, and e-mail; manual rekeying of information from one entity to another; and the fact that trading partners each had their own proprietary IS were considered the primary causes contributing to a lack of real-time information sharing in the supply chain. In addition, information transparency problems are worse in *interconnected* extended supply chains, where there is less likely to be a seamless flow of information across multiple tiers. Finally, advanced IT has made limited progress to date in solving these information problems. We next discuss more fully the various technical solutions that have been deployed and the evidence relating to their limited effectiveness.

Various IT-Based Solutions to Information Transparency Problems in Supply Chains

Among the IT-based solutions for information transparency problems in supply chains are EDI, vertical industry data and process standards, and coordination hubs. We consider each of these solutions in this section, developing a coherent set of propositions that form the contours of a theoretical framework regarding the dual roles of industry standards and IOS architecture in solving information transparency problems in interconnected and extended supply chains.

Electronic Data Interchange

EDI was the first computer-based technology developed to address information problems in supply chains. Large, technologically sophisticated companies have achieved noteworthy successes with EDI. Mukhopadhyay and colleagues [53] determined that Chrysler had savings from the use of EDI that amounted to $60 per vehicle. Other well-known success stories include McKesson [21], Baxter [62], Brun Passot [37], Chrysler, Japan Airlines [14], Fedex [72], Sabre [18], and Enterprise Rent-A-Car [57].

Despite these successes, EDI has delivered far less in its 30-year career than it promised, largely because of limited adoption. Few small organizations have adopted EDI, and usually only when required to do so by their partners [34]. Markus [47] further argued that small organizations resist EDI because they generally do not benefit from its use. Reasons for this include (1) high costs; (2) few partners and transactions, mitigating potential savings; (3) lack of knowledge as well as the resources to implement EDI; and (4) limited ability to reuse EDI investments with other partners because of the lack of standardized transactions, processes, and technology environments [15, 51, 64]. Although EDI-over-Internet is bound to increase the use of electronic transactions, research examining Web-based EDI suggests that it often requires smaller participants to reenter data from internal systems into a Web-based system, rather than fostering true integration across systems [3, 4]. Hence, it is unlikely to contribute much to the achievement of seamless information flows across the supply chain [3, 40].

Further contributing to the reluctance of some suppliers to adopt EDI is a history of antagonistic relationships between large manufacturing firms and their suppliers in large Western industrial nations [5]. This has especially been the case in the automotive industry, where OEMs (e.g., General Motors, Ford Motor Company, and Chrysler) believed it was necessary to drive hard bargains with their suppliers in order to compete most effectively with their peers. An additional way in which OEMs exerted power over their suppliers was by forcing them to conform to OEMs' preferred ways of conducting commercial activities, such as ordering and invoicing: OEMs insisted that suppliers conform to the OEMs' specifications for IT-supported coordination [26, 68]. One consequence was that major automotive suppliers had to maintain parallel systems, both for computer-aided design and for electronic data exchange, at considerable cost to the suppliers' bottom lines [11].

Small suppliers fared worse because EDI investment costs tended to be quite large relative to their scale of operations and the potential benefits they could derive. Not surprisingly, some suppliers chose not to participate, even if it cost them customers [8]. Part of the problem is that proprietary IOS arrangements are often designed by large customer companies with little or no attention to the needs of the partners [13, 26]. In short, for numerous reasons, EDI has not solved information transparency problems in interconnected extended supply chains.

Vertical Industry Data and Process Standards

The advent of Internet standards provides various ways for business communities to address the limitations of EDI. The Internet reduces telecommunications costs, especially for small enterprises. XML makes electronic transactions understandable to humans as well as to machines, and allows for more flexibility (easier changes) than EDI's rigid record and transaction formats. When combined with a renewed effort to standardize business terms and business process flows, Internet standards and transmission are believed to go a long way to reducing the barriers that have prevent widespread EDI adoption.

Industry-wide data and process standards can contribute to solving supply chain information transparency problems by lowering the costs for suppliers of adopting electronic business transactions. Such standards lower adoption costs by providing IT products and services providers with incentives to build the standards into their solutions and by enabling suppliers (particularly small and peripheral ones) to reuse their IT investments with multiple customers.

The best-known instance of Internet-era industry-wide data and process standardization is RosettaNet in the high-tech industries [1, 7, 46, 54]. Adoption of RosettaNet standards appears to be increasing (at least among Asian suppliers [7]), and RosettaNet standards have formed the basis for advanced private coordination hubs, discussed below.

Among the other industries in which a major XML-based standardization initiative has taken place is the mortgage industry [49, 71]. Markus et al. [49] showed that successful standardization efforts, such as the Mortgage Industry Standards Maintenance Organization (MISMO), require balancing the needs of participants with different interests while preventing powerful interests, such as IT providers or large customers, from being able to appropriate all the benefits of the standard's adoption. Key to achieving this balance is to redirect the focus away from the use of proprietary formats and platforms that may be used in the belief that they offer competitive advantage. Markus and colleagues [49] explained that participation in industry-wide standards efforts is facilitated by the recognition that "we do not compete on" proprietary data formats. Furthermore, participants in industry-wide standardization efforts can benefit in various ways other than simply having the standard to use; for instance, they can benefit by making sure that the standard is more specifically tailored to their own needs.

XML-based standards initiatives have also arisen in the chemical and insurance industries, among others. These initiatives are more promising in their prospects for widespread adoption than traditional EDI, although it is still too early to estimate their eventual penetration.

This discussion of vertical industry standards and IOS adoption leads to our first proposition:

> *Proposition 1 (Industry-Wide Data and Process Standards and Adoption): If industry-wide data and process standards are used in the development of a global supply chain IOS, then adoption by smaller and more peripheral participants is more likely than if a proprietary system is used.*

Point-to-Point Architectures, Adoption, and Information Transparency Problems

Despite their promise, XML-based data and process standards retain important limitations when it comes to addressing the information transparency problems of interconnected extended supply chains. Even though such systems may be less complex than EDI, many small organizations lack the expertise to implement XML standards and depend on IT products and services providers to write the standards into their software offerings. Even more important, just as with EDI, XML-based standards are often implemented on a point-to-point basis. This means that there is still the possibility that the flow of information through the supply chain will be less than seamless if some parties opt out of using the standards or if changes are made to the easily extensible formats that inhibit chain-wide coordination. As a consequence, members of a supply chain may still face high costs for implementing and maintaining separate connections with different partners, and thus will have lower incentives for adopting the IOS, despite it being standards based.

Hence, we argue that industry-wide data and process standards are necessary, but not sufficient, to solve information transparency problems in supply chains if they are implemented on a point-to-point basis. Point-to-point architectures can still result in problems such as the bullwhip effect because information transmission remains sequential, which means that there is potential for delays, inefficiencies, and errors. Failure to solve supply chain information transparency problems is particularly likely if some members of the extended supply chain fail to adopt standards-based electronic communication. These problems of point-to-point architectures are summarized in the following two propositions:

> *Proposition 2 (Point-to-Point IOS and Adoption): If a supply chain IOS is implemented on a point-to-point basis, even though based on industry-wide data and process standards, it may not be widely adopted by all extended supply chain members.*

> *Proposition 3 (Point-to-Point IOS and Information Transparency): If a supply chain IOS is implemented on a point-to-point basis, then information transparency problems are unlikely to be solved.*

In contrast to point-to-point architectures, hub-based systems have been developed to complement industry-wide standards and move one step closer to seamless communication in the extended supply chain. They may be private (i.e., limited only to invited business partners) or shared such that competing companies can use the same standards-based systems. A hub architecture promotes information transparency by making information available to all relevant organizations simultaneously, rather than sequentially and bilaterally. Moreover, as stated in Proposition 1, when standards based, greater adoption by smaller and more peripheral members of the supply chain is likely, which further improves the resilience of the supply chain IOS to information transparency problems by reducing the need for data reentry. This is summarized in the following proposition:

> *Proposition 4 (Standards-Based IOS Hubs and Information Transparency): If a supply chain IOS uses a standards-based coordination hub architecture, then it will be more likely to solve supply chain information transparency problems than if it uses a point-to-point architecture.*

Private Coordination Hubs

Private coordination hubs are designed by the dominant companies in supply chains (often called "supply chain orchestrators") for use by business partners. They are private in the sense that only invited business partners can participate. Two notable examples are the hubs developed by Intel and Net-Tech (a pseudonym). The descriptions below were adapted from Cartwright et al. [12] (for Intel) and Leser et al. [45] (for Net-Tech).

Intel, the world's largest chip manufacturer and a leading manufacturer of computer networking and communications products, was a founding member of the RosettaNet consortium. After 2000, Intel aggressively redeveloped its IT architecture using RosettaNet standards to reduce costs through greater process automation and to create new business value through supply chain models involving outsourcing to third-party logistics companies. Intel estimated the benefits from these changes to be $40 million in 2004 alone [12].

A key challenge Intel faced was the heterogeneity of *its* own IT architecture: Intel used a variety of enterprise resource planning (ERP) systems in different parts of its business. Each ERP system had its own infrastructure of operating system, databases, and interfaces. Intel realized, first, that modifying its own internal systems to comply with RosettaNet standards would be expensive and time-consuming. Second, Intel realized that the company needed to shield the complexity of its enterprise IT architecture from its partners. Therefore, Intel created a reusable middleware platform to support the passing of standardized RosettaNet messages between its back-end systems and those of its business partners.

A second key challenge Intel faced was heterogeneity of the IT environments, technical skills, and financial resources of its *business partners.* The thousands of companies in Intel's extended supply chain had the ability to perform some type of electronic transmission, but they varied considerably in their specific capabilities. Many used EDI, others used file transfer, others had even more limited capabilities. All would face significant conversion costs to adopt the RosettaNet standards on which Intel's platform was built. Therefore, Intel decided not to mandate the use of RosettaNet standards, but rather to give its partners a range of options by which they could connect to its platform, including RosettaNet, EDI, File Transfer Protocol, and a suite of four basic Web-based transactions (purchase orders, forecasts, invoices, and advanced shipment notifications) for the least IT-sophisticated companies.

A second example of a private coordination hub is that developed by Net-Tech. The company is a major networking solutions provider that orchestrates a complex, multitier supply chain consisting of manufacturing partners, to which it outsources production, and component providers, which supply the parts needed in the manufacture of Net-Tech's products [45]. Historically, Net-Tech communicated sales forecasts and purchase orders to manufacturing partners, which in turn exchanged forecasts and purchase orders with component providers. This process had two drawbacks. First, because of the sequential nature of the data flow, crucial information—about back-ordered parts, for example—sometimes did not reach Net-Tech in a timely fashion.

Second, because of the heterogeneous information-processing environments of the supply chain partners, a variety of errors and "disconnects" occurred when the partners exchanged information.

Consequently, Net-Tech developed a RosettaNet standards-based collaboration hub to connect the company simultaneously with all tiers of its supply chain and to standardize information exchange and allow for data aggregation, dynamic process monitoring for exception reporting, and enhanced performance analysis and collaboration capabilities. Net-Tech was not willing to consider a consortium-type arrangement that would be open to its competitors because the company believed that better supply chain management would give it significant competitive benefits, and Net-Tech was large enough to afford a closed solution. Net-Tech chose Viacore, an IT solutions provider, to develop the hub and to bring Net-Tech's partners on board.

Private coordination hubs augment industry-wide data and process standards with an IT architecture that eliminates the point-to-point communication that can create delays and errors. At the same time, private hubs have one major drawback from the point of view of small and peripheral supply chain members. These hubs can be used only for the portion of their business that these organizations conduct with a supply chain orchestrator. Thus, suppliers are still forced to bear the costs and inefficiencies of using duplicate procedures and technologies across the companies with which they do business. Not surprising, Intel found small and medium-size enterprises slow to adopt RosettaNet standards, which are the most seamless way of integrating with its coordination hub [12]. In addition, the previously mentioned Cisco case shows that private coordination hubs cannot always eliminate transparency problems in extended supply chains. The following proposition summarizes this analysis:

> *Proposition 5 (Private Standards-Based IOS Hubs and Adoption): If a supply chain IOS is implemented as a private standards-based coordination hub, then it will face adoption problems by smaller, remote, and peripheral members of the supply chain.*

Shared Coordination Hubs

In some industries, initiatives involving shared coordination hubs appear to be addressing a broader range of information transparency problems facing extended supply chains. One example is the chemicals industry, in which a private company, Elemica, provided XML standards–based electronic interconnections to all organizations wishing to transact business using its platform [48].

Another example is the New England Healthcare Exchange Network (NEHEN),[1] founded in 1998 to provide a collaborative environment within which hospitals and other providers could communicate with health insurers and health maintenance organizations in a standardized and cost-effective manner. NEHEN employed a peer-to-peer network with a server at each member site that translated messages from internal data formats into health-care industry EDI standards for transmission via a gateway. Supported transactions ranged from patient eligibility requests requiring a real-time response to large batches of transactions containing remittance advice for payment for services rendered. No central data repository was maintained. The costs of participation were kept low through an "open source" policy that makes software interfaces developed by any member available to all others. Membership costs were more than offset for large members by elimination of EDI value-added network transaction fees and multiple channels/processes for different partners. Smaller members benefited to a lesser extent owing to their smaller transaction volume and lower levels of automation. Members of the NEHEN consortium were working to make the shared infrastructure even more attractive to smaller members by innovative pricing schemes and by encouraging software vendors to build NEHEN connectivity into packaged clinical IS.

The shared coordination hub solution also appears to be applicable to global extended supply chains similar to those in the automotive industry. For example, the Information Technology for Adoption and Intelligent Design for E-Government (ITAIDE) project [60] aimed to increase the security of international trade while reducing administrative overhead, by finding the right balance between control and cost of information gathering. The project studied four industries (beer, paper, drugs, and food) in Europe, taking a similar approach in each. Process redesign and innovative ITs (a smart container seal, service-oriented architecture, and open standards) were used to generate trade simplifications and to enhance control and security. For example, the Beer Living Lab (BLL) addressed the export of Heineken beer from the Netherlands in seagoing containers—a supply chain that also included Dutch tax and export authorities, shipping agents, security agencies, and IT products and services vendors (IBM, SAP, and EPCglobal). A key element in the ITAIDE project was the use of the Electronic Product Code Information System (EPCIS) data standards developed by EPCglobal, a subsidiary of GS1. Each player in the supply chain runs its own EPCIS-conforming systems that publish data accessible to partners on a need-to-know basis. For example, Safmarine, a subsidiary of the Danish shipping line Maersk, replicates logistical data, such as the bill of lading, into its EPCIS-based system. Overlaid on the assemblage on company-internal systems is a component called a "Discovery Service." It is the unifying element through which data, transmitted via the EPCglobal Network, is shared among partners. ITAIDE efforts are aligned with parallel developments by the World Customs Organization and is in compliance with the UN/CEFACT (United Nations Centre for Trade Facilitation and Electronic Business) Core Components Technical Specification (CCTS).

In short, shared coordination hubs appear to provide the information transparency aspired to by the supply chain orchestrators that build private coordination hubs. However, because shared hubs can be used by suppliers of any other customer participating in the hub, shared hubs reduce some of the barriers that have historically prevented full adoption of EDI, vertical industry XML-based data and process standards, and private coordination hubs. Instead, adoption of shared hubs is likely to be more extensive by small, remote, and peripheral supply chain members. Hence, we propose:

> *Proposition 6 (Shared Standards-Based IOS Hubs and Information Transparency): A supply chain IOS implemented as a shared standards-based coordination hub will be more likely to solve supply chain transparency problems than private standards-based coordination hubs.*

Methods

Testing propositions such as those provided above would require careful comparative analysis for which data are currently lacking, given the relative recentness of Internet-era standards-based coordination hubs. However, single, "revelatory" case studies can often shed useful light on important issues when the available data are limited [74]. We next describe a case in which a standards-based shared coordination hub showed promising improvements in supply chain transparency, whereas earlier efforts that did not employ industry-wide standards or were not shared did not succeed. In particular, we explore our propositions through a detailed case study of the development and implementation dynamics of an IOS standard within the automotive industry. This industry provides an excellent context for exploring our propositions for a number of reasons: in the United States, this industry represents a significant share of both workers (6.6 percent) and the gross domestic product (2.3 percent), even after the dramatic recession it faced in 2008–9 [56]. Automotive manufacturers have large and complex supply chains [70], and have experienced rapid growth in the extent to which parts are imported from overseas [50]. Finally, automotive manufacturers have a long history of less than successful efforts to employ IOS in the supply chain [11, 26].

Within this industry context, our case focuses on the IOS efforts of a large U.S. automobile manufacturer. We provide a brief history of efforts by one automotive manufacturer (we refer to it as AutoInc) to connect electronically with its supply chain and contrast these past efforts with new work being completed by AIAG to define standards for long-distance automotive supply chains. AIAG is a nonprofit industry association founded in 1982, the members of which include automotive manufacturers, parts suppliers, technology vendors, and other service providers. Its charge is to promote standards development and harmonized business practices in the automotive industry. Our work with AIAG is one component of a project funded by the National Science Foundation (NSF) exploring the diffusion of industry-wide IS standards.

Data sources for the study include a dozen in-depth interviews conducted with automotive industry and AIAG representatives starting in late 2007 and continuing into early 2010—essentially throughout the history of the AIAG standards-making effort. We also reviewed numerous documents provided by the AIAG working group as well as by other interviewees. Among the interviewees were a former director of logistics at AutoInc; several AIAG staff members working to support the standards effort; a representative from the Original Equipment Suppliers Association (OESA), the major association representing automotive industry suppliers; the chief executive officer (CEO) of a logistics software technology firm participating in the AIAG working group; representatives from the NIST collaborating on the AIAG effort; and a logistics manager from another automotive manufacturer who also participated in the work on long-distance supply chain standards. This AIAG standards-making effort is known as the Materials Off-Shore Sourcing (MOSS) project.

All of the interviews were recorded and transcribed and served to inform us of key events and insights regarding past and present efforts to establish an interconnected supply chain. Our analysis is based on a single case study, and we use it to help build theoretical insights for further empirical investigation. The historical comparison of past efforts by AutoInc to implement proprietary systems to current experiences participating in the development and pilot testing of an industry standards–based system provides a context for assessing our propositions as well as to develop further insights to guide future research.

Findings from a Case Study: IOS in a Long-Distance Automotive Supply Chain

Our case study examines the AIAG effort to develop data standards and the technical architecture for systems that would enable improved coordination in extended, or long-distance, supply chains, which are defined as supply chains that encompass overseas suppliers shipping parts to the automotive manufacturer via ocean freight. AIAG began the MOSS project in 2006 following requests from major manufacturers for help in improving communication efficiencies in their growing global supply chains. The pilot test for the MOSS project took place between a large automobile manufacturer, one of its suppliers, and other supply chain participants (e.g., ocean carriers). This "trade lane" offered a realistic test site to consider the practical and theoretical implications of a standards-based collaboration hub approach. This case also represents a good context for exploring our propositions for the following two reasons:

1. The automotive industry exemplifies an industry structure highly reliant on complex and increasingly global supply chains with a strong need for improved IS integration [11, 58, 64, 70]. Moreover, the relationship between manufacturers and supply chain partners in the automotive industry has been characterized at times as adversarial [52], making it a difficult context within which to implement cooperative IOS that would enhance transparency.
2. The case study company had a history of failed attempts to implement proprietary and point-to-point IOS with its supply chain partners. These prior efforts serve to strengthen the arguments that an alternative approach is needed and that a standards-based coordination hub approach may result in greater adoption.

The Growing Need for IOS in the Global Automotive Supply Chain

As noted earlier, NIST researchers found that the U.S. automotive sector wasted more than $5 billion annually due to shipment delays, order cancellations, and forecast revisions [70]. Further indicators of the scope of the problem were identified in a survey of transoceanic shipping practices in 210 companies commissioned by AIAG in 2005 and conducted by AMR Research [22]. Eighty-seven percent of the responding companies felt that they lacked visibility in the supply chain, while 91 percent reported problems emanating from use of phone, fax, and e-mail. A full 79 percent reported rekeying shipment data multiple times into trading partners' proprietary systems. At the same time, reliance on overseas imports grew 52 percent in the five years preceding the survey. In total, respondents estimated that 15 percent of in-bound shipments experienced delays because of incomplete data. As a result, respondents resorted to maintaining excess transit and safety stock inventory, and were forced to pay higher costs for expediting shipments when delays were intolerable. Incomplete information also put shipments out of compliance with U.S. Customs and Border Protection, leading to additional delays.

The increasing reliance on overseas imports presents a daunting problem for information transparency in supply chain information. In addition to the challenges of the lack of an adequate data network infrastructure in some overseas locations, full systems integration is all the more difficult because of the number of participants in any long-distance supply chain. Participants can include the manufacturer, suppliers, 3PLs, freight forwarders, customs brokers, customs agents, ocean carriers, and others. In research conducted for the MOSS project, AIAG identified 30 different documents containing in excess of 400 data elements [50]. It is not surprising, then, that there was so much inefficiency in communications in global automotive supply chains. As stated by one interviewee:

> The more global you get, the more transparency you lose in your supply chain, and the more you don't know what's going on. (AIAG MOSS Team Representative)

Past Efforts at Proprietary IOS in the AutoInc Automotive Supply Chain

During the course of our case analysis, several major efforts by one automotive manufacturer to establish electronic integration with its supply chain were described by interviewees. Table 1 highlights four of these efforts, three of which were outright failures, while the fourth exhibited some success. The initial three examples illustrate what has happened in this company when supply chain IOS were not industry standards based, did not have an architecture that delivered needed information to all of the necessary participants in a simultaneous fashion rather than sequentially, or otherwise failed to provide for equitable distribution of benefits. The one modest success, example 4 in Table 1, did involve a standards-based approach, but focused only on a small fraction of the supply chain—the connection between truckers and customs officials at the Canadian and Mexican borders. Nonetheless, it suggests that relying on industry-wide standards can improve the rates of adoption by supply chain partners, especially among smaller players that have not embraced IOS in the past. This experience is consistent with our Industry-Wide Data and Process Standards and Adoption Proposition (P1).

The first table entry describes a point-to-point in-house system that AutoInc developed and attempted to require all its supply chain partners to use. Although AutoInc paid for the system, it required significant training and effort by the supply chain partners, as illustrated by the following quotations:

> [AutoInc] spent $5 million on [its system]. It was a point-to-point system designed to get the right data entered, but it was not truly end-to-end. (AutoInc Logistics Manager)

Table 1. Prior Efforts by AutoInc to Achieve Electronic Integration in Its Supply Chain

Date	AutoInc Supply Chain Integration Efforts
1. Early 1990s	AutoInc developed an in-house point-to-point IOS system that required supply chain partners to enter data in the proprietary AutoInc system. It was resisted by supply chain partners due to high labor and training costs and failed.
2. 2000	AutoInc joined with other automotive manufacturers to create Covisint, a business-to-business electronic marketplace linking automobile makers with suppliers. The marketplace failed in part because it was viewed by suppliers as a means of forcing down prices. Hence, benefits were not shared equitably among the participants.
3. Early 2000s	AutoInc attempted to consolidate logistics with an outsourced solution, establishing a company in partnership with a global logistics provider, again built on a proprietary, point-to-point approach. Ultimately, this effort did not yield expected benefits, and the logistics operation was reintegrated into the company in 2007.
4. 2001 and later	AutoInc participated in the National Customs Automation Program (NCAP) and the Free and Secure Trade (FAST) initiative led by the U.S. Customs and Border Protection. Advance electronic shipping data shaved hours off truck transit time at Canadian and Mexican border crossings. Trucking firms working with AutoInc were able to redeploy trucking assets more quickly for other business, and were willing to adopt the FAST system.

Sources: AutoInc Logistics Manager and [33].

> The costs were to be borne by all the users. Freight forwarders were asked to use the system to enter their data. This was costly to them in terms of people and training; they asked for funding from [AutoInc and] didn't get it, so the system died in its tracks. (AutoInc Logistics Manager)

Because the solution was point-to-point in design, the response by the freight forwarders follows the expectations from the Point-to-Point IOS and Adoption Proposition (P2), which suggested that widespread adoption of such systems would be unlikely. In addition, the fact that this system was not truly end-to-end means that it would not have solved AutoInc's information transparency problem even if it had been used, as suggested by the Point-to-Point IOS and Information Transparency Proposition (P3).

Supply chain partners such as the freight forwarders had little incentive to invest their time and effort on a system that could not be used with other trading partners. From a theoretical perspective, the interconnected structure of the supply chain—in the sense that freight forwarders participate in multiple supply chains led by multiple manufacturers—mitigated the adoption of a proprietary system.

The problem of interconnected supply chains extends to more than just the freight forwarders. For example, an interviewee who represented automotive suppliers noted that many smaller parts suppliers serve multiple manufacturers and could not be expected to adopt each manufacturer's proprietary IOS:

> [T]he supply chain in automotive is so complicated and there's so many low-tier suppliers that serve so many different customers that investing in EDI is expensive for them and complicated. (OESA Representative)

In the second example in Table 1, the failure of Covisint illustrates the importance of attending to equity in the distribution of IOS benefits. Although the main manufacturers attempted to create an industry-wide solution by involving several major manufacturers, its original implementation was viewed by suppliers as a means to force prices down through competitive bidding [26, 33]. Moreover, suppliers felt they would be coerced to participate, and the IOS literature has argued in the past that coercion generally results in less than optimal adoption and use of IS [29, 30, 47].

> [T]his really grew out of the whole Internet bubble and e-business was some new thing in 2000 or 1999. And, there was a lot of furor because the OEMs, or the car manufacturers, were suddenly all on the bandwagon of transacting pretty much everything electronically. And supplier companies were expected and anticipated being asked to come along. (OESA Representative)

Although Covisint did represent an effort to create an industry-wide solution, we have proposed that trying to build IOS on standards is by itself insufficient to solve the problems of information transparency across the broader set of participants in the supply chain. As observed by our supplier representative:

> I think this kind of served to underscore the fact that developing standards, or harmonized standards, for electronic transactions in this industry is a huge challenge. I mean we saw a lot of plans fall apart and we saw a lot of companies waste a lot of money. (OESA Representative)

The third effort illustrates that outsourcing the implementation of logistics systems to a third-party company was also not the solution to overcoming the adoption and implementation problems experienced by AutoInc with their in-house approaches. The IOS systems remained proprietary, facing the same incentive problems for adoption and use that earlier in-house efforts faced. This experience is indirectly consistent with our fifth proposition: Private Standards-Based IOS Hubs and Adoption.

From our interview with AutoInc's former logistics manager, we learned that only the fourth effort (see Table 1), a true standards-based approach to electronic exchange with supply chain partners, had experienced some success. FAST (Free and Secure Trade) addressed more than the manufacturer and the supplier, also involving freight forwarders and customs officials, and so included more components of an extended supply chain. As our interviewee explained, the success of FAST inspired AutoInc and other industry participants to extend this broader, standards-based effort to ocean freight:

> FAST showed that it could be done with trucking shipments to and from Canada, but now with MOSS, we are extending this to the more complex ocean freight system. FAST created many of the basic elements of MOSS, but "ocean" is more complicated than land trucking. (AutoInc Logistics Manager)

Overall, our analysis of past efforts by AutoInc highlights the problems that the automotive industry has experienced in developing true electronic integration in the supply chain. Prior AutoInc IOS were proprietary or did not rely on industry standards and their various outcomes generally support the pattern of predictions in our propositions regarding IOS adoption and information transparency. The point-to-point nature of existing systems did not provide the information transparency needed by supply chain participants. The IOS, with the exception of the FAST precursor to MOSS, yielded little partner benefit, and actually increased supply chain partner costs. IS researchers have long recognized that the sustainability of any IOS depends on the extent to which all parties benefit [20]. The end result is often that the systems that do get implemented, especially if by mandate, yield only superficial adoption, as evidenced by this supplier's comment:

> I know a lot of people still who get the electronic stuff and they type it into their own Excel spreadsheets and they use that to run the manufacturing side of their business. (OESA Representative)

As we show next, the attributes of MOSS as a standards-based supply chain coordination hub for the entire industrial community represent a new approach with important differences from the failed efforts of the past.

The MOSS Project: A Standards-Based Approach to IOS in an Extended Supply Chain

In stark contrast to earlier, proprietary efforts, our case analysis revealed initial signs of success in a recent pilot implementation in one AutoInc supply chain using the MOSS standards developed in conjunction with AIAG and NIST. AutoInc joined with other manufacturers, IT and logistics service providers, suppliers, U.S. customs representatives, and NIST to work on an industry-wide solution to the problem. Although the results are preliminary, after conducting a pilot test in one AutoInc trade lane with a Korean supplier of battery parts, the supplier was not only willing to continue with and extend the pilot program, it offered AutoInc improved terms of trade because the benefits received by the supplier were so valuable.

The MOSS project progressed through several major stages, including analysis of baseline metrics, development of process diagrams and use cases, creation of data tables, a lab-based proof of concept, and the actual pilot test in a field setting. Following the pilot test, project leaders developed a detailed cost-benefit analysis and a set of implementation guidelines [23, 50]. We provide a brief description of each stage in Table 2.

Table 2. Stages of the MOSS Project

MOSS project stage	Description of AIAG MOSS team activities
1. Identification of the problem and development of baseline metrics	Surveyed manufacturers regarding their international shipping experiences to identify problems, and assessed average times that shipments took from supplier to manufacturer, including dwell times at intermediate nodes in the supply chain.
2. Developed process diagrams and use cases	Diagrammed the flow of goods through the supply chain and identified the specific data elements required in each transaction needed to support this flow of goods.
3. Created data tables	Provided precise technical definitions of all data elements needed to populate documents that supported shipments in a supply chain, and mapped these definitions onto existing EDI standards.
4. Proof of concept	Used the identified data elements and process diagrams to simulate transactions in order to ensure that the emerging standards adequately addressed supply chain requirements, and to see what proportion of the data is reused as goods moved through a supply chain.
5. Pilot test of MOSS standard	Tested the MOSS standard in a software system with a specific supplier–manufacturer relationship over a three-month period alongside an existing system to assess whether it supported fully electronic transactions and provided needed visibility to partners.
6. Preparation of cost-benefit analysis	Used the pilot test results to estimate the costs and benefits of using the MOSS standard in automotive supply chains.
7. Preparation of implementation guidelines	Provided a detailed description of how to implement the MOSS standard based on different user situations.

Source: [50].

The project began with AIAG commissioning a study to assess the typical international shipping experiences by manufacturers. They asked study participants to provide details about the documents and information used in their international parts orders, and gathered data on the times that ordered goods take to move from the supplier's premises until reaching the buyers' warehouses along with the dwell times at the various points along the way. Among the more interesting baseline metrics was a finding that helped to illustrate the potential payoffs from MOSS. In the 30-odd documents used for overseas shipments, 92 percent of the information contained in them is known at the start, while only 8 percent is generated en route [50]. Baseline data on average transit and dwell times at various points in the shipping process also helped to identify the potential savings that would result if data reentry were eliminated; analysis showed that earlier provision of shipment data decreased dwell times (Table 3).

The AIAG team, in consultation with NIST researchers, developed formal data definitions and transaction descriptions that would ultimately form the core of the MOSS standard. These elements were then fed into a "proof of concept" test conducted by

Table 3. Baseline Measures of Transit and Dwell Times in Long-Distance Supply Chains

Transit Route	Days
Transit from supplier to consolidator	3.78
Dwell at consolidator	7.38
Transit from consolidator to port of departure	1.12
Dwell at port of departure	7.49
Transit from port to port	10.09
Dwell at port of entry	4.39
Transit from of entry to final destination	4.62
Total transit time	36.02
15.8 percent of shipments took over 45 days	
Range: 20 to 64 days	

Source: [50].

Note: Based on 526 data points.

AIAG and NIST. This laboratory test of the emerging MOSS standard focused on a subset of the full set of supply chain transactions that had been identified. The AIAG/NIST analysis focused on 75 data elements used between the supplier, 3PL provider, freight forwarder, ocean carrier, customs broker, and buyer. They simulated the creation of prepopulated documents that would be needed for the transactions between each supply chain participant for a shipment to move from supplier to buyer. The idea was to investigate how well the MOSS standard captured the actual data flows that would be needed. According to their analysis, approximately 80 percent of data elements in their lab test needed to be input only once and then could be reused in subsequent invoices and customs documents [23, 50].

In order to enhance visibility across the supply chain, the MOSS team made two technology decisions. First, they relied on United Nations e-Docs—existing global EDI standards for invoices onto which the identified data elements were mapped. This decision meant that they would not have to develop electronic documents from scratch and could benefit from the fact that many large shipping companies already were familiar with and used these documents. In addition, the use of standards was expected to increase the chances of adoption as we predicted in our Industry-Wide Data and Process Standards and Adoption Proposition (P1). Second, in order to minimize the cost and complexity of these EDI-based documents, the team decided on a cloud-based architecture with a "software as a service" (SaaS) solution (Figure 1). This technical approach was a critical decision that was aimed at helping to avoid having the MOSS pilot face the same limitations as prior point-to-point systems. Rather than moving data sequentially from each supply chain participant to its adjacent participant as the goods are transported, the architecture permitted true visibility of the status of the shipment to each partner that needed this information, even if they were not the next in line to receive the good. It thus represented a good test of our fourth (Standards-Based IOS Hubs and Information Transparency) and sixth (Shared

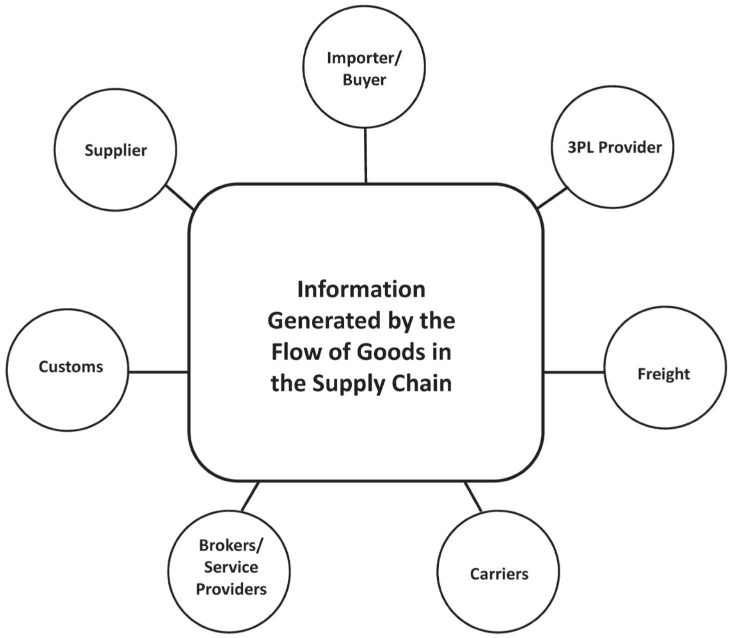

Figure 1. The MOSS Project's Cloud-Based Architecture for a Supply Chain IOS
Source: Adapted from [50].

Standards-Based IOS Hubs and Information Transparency) propositions. Through the cloud-based system, as each participant enters data, it instantly becomes available to the entire supply chain, depending on the business rules defined for each type of document. Each participant's documents can then be prepopulated with previously entered data, and participants are notified when shipping events occurred, improving their ability to forecast shipment arrivals. Multiple software providers were included in the project, and NIST developed conformance tests to ensure that any software was in compliance with the standard.

The interconnection vendor selected for the pilot test brought a unique pricing approach to the project that addressed the issue of equity in costs and benefits that so plagued earlier IOS efforts in the industry. The company charged a fee for use of the system only to the importer of the parts—it was free for all the other parties. The following quotation from the CEO of the software provider illustrates his rationale for the pricing approach—that those who benefit the most should pay for the service:

> [O]ur pricing model typically with our customers is based on a transaction fee. It will be free for [the different parties]. They will not be paying anything for that at all. . . . The benefit is to improve the [AutoInc] supply chain network, and today if there is any delay, [AutoInc] will pay for any expedited service. [AutoInc] gets the benefit and should pay per transaction. (Logistics Software Company CEO)

The pricing approach and SaaS architecture was a benefit especially to the smaller companies in the supply chain that might not have the resources to implement complex IT solutions. In fact, participants can use a simple browser to access the data in the MOSS system if they want. Overall, the MOSS architecture and pricing approach lowered the costs of smaller and more peripheral participants over earlier IT-enabled solutions, and reduced the extent of training and effort that had been associated with the implementation of complex systems in the past.

The MOSS Pilot

From May to July 2009, a three-month pilot study was conducted by the AIAG MOSS team in a U.S.–Korea trade lane. Trade lanes refer simply to the origin and destination locations for international shipping, such as Korea to the United States, or Germany to the United States, and include the various elements involved such as in-country transit, ports, and ocean shipping. The MOSS pilot involved purchases of battery parts from a Korean supplier, which were shipped to a warehouse in Kansas City. This trade lane annually executes 1,379 shipments worth $55 million. The scope of the pilot included ordering, transport, and customs processes, but not payment [50]. During this time, the MOSS system operated in parallel to the existing systems, using live data to examine whether the expectations were met regarding lack of errors in MOSS data flows as well as the ability to input most data once and then populate forms and provide visibility to other supply chain partners. In this fashion, AIAG researchers were able to measure when information became available and the extent to which any rekeying was necessary. Based on these measures, and using what AIAG researchers believed were conservative assumptions about how earlier access to information could translate into shorter dwell times at both the port of loading and the port of entry, various estimates were developed of the potential savings if MOSS had been used [50]. We report these estimates from the AIAG cost-benefit analysis in the following paragraphs, but caution that they are merely projections based on a series of assumptions that the AIAG MOSS team made from the pilot experiences, rather than on actual measured savings from ongoing use of MOSS.

The MOSS Pilot Results

At the conclusion of the pilot, a detailed cost-benefit analysis was completed, estimating the potential savings that might have been realized had the MOSS trade collaboration system been deployed. One of the key findings was that 100 percent of the data entered at the outset of each shipment was able to be reused at a later point. In contrast, with the current process, only 21 percent of the data can be reused. Nearly half of the data (49 percent) is entered more than twice during the shipping process by different parties.

The AIAG cost-benefit analysis [50] provided a range of labor, time, and cost savings in the pilot. Based on the extent of reuse of data, and consequent elimination of rekeying requirements, AIAG estimated that the number of tasks that needed to be performed in the shipping process could be reduced from 26 to 9, which would result in labor savings. They further estimated that a reduction in shipment dwell time at the port of loading and port of entry of 4.85 days could be achieved as a conservative performance estimate. Essentially, the rationale for the assumptions of reduced dwell times came from the AIAG study of long-distance supply chains, where they found that shippers built extra days into shipping schedules to deal with the time spent resolving errors in the information used to meet documentary requirements for the goods being shipped. They postulated that roughly 50 percent of the average of 8.81 days of dwell time at the port of lading (4.41 days) could be eliminated, and 10 percent of the average of 4.31 days of dwell time at the port of entry (0.44 days) were reasonable performance goals, if the extra days were not needed. These lower dwell times would result in reduced working capital for in-transit inventory, in addition to lower transportation costs and lower customs fees. AIAG researchers ultimately arrived at a possible savings up to 1.42 percent of the trade lane's total annual import value of $55 million, or $784,000 [50].

In addition to the reduced working capital from lower in-transit inventory, other one-time savings were projected by the MOSS team. Given the shorter transit times and improved planning that better visibility offers, AIAG researchers estimated that AutoInc could reduce its annual buffer inventory needs by 7 days' worth of inventory (1.9 percent or 7/365). This translated to just over $1 million in savings from the $55 million in annual imports in the trade lane. Together the working capital and buffer inventory savings for AutoInc were projected to be $1.8 million with the use of MOSS in the AIAG cost-benefit study [50].

Ongoing savings were further projected based on lower financing costs of the smaller inventories, reduced fees because of greater efficiencies and fewer problems in carrying out information tasks, and labor savings from the reduced task count. MOSS researchers estimated that these ongoing savings amounted to approximately $392,000 in this trade lane [50].

Finally, the AIAG researchers extrapolated the various direct and ongoing savings to other trade lanes within the AutoInc organization by applying the same percentage reductions estimated in the pilot trade lane to AutoInc's total import value. This resulted in a projected savings of $50 million in one-time costs and $10 million in ongoing savings annually. Applying the same extrapolation approach to the total import value of the entire automobile industry—estimated at $52 billion—the AIAG cost-benefit analysis document projects a potential savings of $1.7 billion in one-time costs and $370 million in ongoing annual savings if the MOSS standards were universally used in all supply chains [50].

Other benefits observed in the pilot included improved visibility, better error detection, higher conformance with new customs regulations, and efficient use of resources. The visibility in the supply chain allowed AutoInc to engage in better planning and forecasting. Error detection was best illustrated by one event taking place during the pilot test. Workers at the receiving warehouse in Kansas City had long assumed that each pallet from the Korean supplier held 32 batteries, and reorders were made based on the assumed level of inventory in the warehouse. It was only when the faulty received shipment data were sent to the supplier via MOSS standardized documents that the warehouse workers were made aware that, in fact, each pallet held 42 batteries. This error had led to an excess supply of batteries in the warehouse, estimated by the Logistics Software Company CEO at two years' worth of inventory.

Greater visibility also provided benefits to the Korean supplier. Specifically, because the supplier was better able to forecast the OEM's demand for production, the supplier could increase its production for other customers' orders, thus improving its own profitability.

Because the MOSS standard was designed with new U.S. Customs and Border Protection rules in mind, shipment data in compliance with security requirements was virtually guaranteed, which can eliminate costly delays at the port of entry. A quotation from one of the MOSS project participants who worked with a global logistics services company illustrates how customs regulations were built into the standard:

> We are not going to get into making any recommendations to change any of the customs standards because it would take too long. Their messages are very stable. We are, however, building in . . . customs initiatives, particularly the importer's security filing. . . . What the DHS [Department of Homeland Security] and customs in the U.S. is requiring is that for every importation by ocean into the United States . . . that a security filing has to be received by customs 24 hours prior to the lading of the goods on the foreign vessel. . . . We're cognizant of that. We're building that into the MOSS solution. (MOSS Participant and Global Logistics Service Provider Representative)

A fourth set of benefits involved the ability of intermediate transportation providers to make more efficient use of their transportation assets. Because trucks and containers can be moved more quickly through the process, they can be redeployed for use with other customers to generate revenue.

As a result of the trial's success, the battery supplier was enthusiastic about continuing with use of the MOSS standard, and even proposed new, more favorable payment terms to AutoInc. The company offered to be paid when goods were loaded on the vessel at the port of lading, rather than being paid when the goods left the factory. This would move inventory ownership from the buyer to the seller for the days when the shipment dwelled at the port, which would result in improved cash flow for AutoInc. In light of historically adversarial relationships between OEMs and suppliers in the automotive industry [52], for a supplier to offer trade concessions to an OEM is a remarkable testament to MOSS's ability to provide *shared* benefits.

MOSS Pilot Summary

The MOSS pilot shows how the combination of standards and an architectural approach (shared coordination hub) can enable data and process transparency (or visibility) in multitier supply chains. Thus, the pilot provides preliminary evidence in support of the Shared Standards-Based IOS Hubs and Information Transparency Proposition (P6). Because participants could use this solution to collaborate with other business partners, this solution addresses the reluctance of small and peripheral players to adopt proprietary solutions. Moreover, unlike many prior IOS initiatives, the MOSS arrangements not only benefited both the buyer and the supplier but also created benefits due to improved information transparency for the many other supply chain partners, including logistics providers that are participants in other manufacturers' supply chains—an additional factor likely to contribute to widespread adoption.

Discussion

The MOSS approach shows great potential for solving the automotive industry's supply chain information transparency problems. It provides preliminary empirical evidence in support of our propositions, to which we return in the next section of our discussion. The MOSS case further suggests three new questions that we believe can guide future research efforts on IOS. These questions additionally speak to potential managerial implications of our analysis. First, how important are the involvement of an industry association and industry-wide participation in the development of IOS solutions? What other conditions might come into play, and what steps can such associations take to increase the likelihood of developing successful solutions? Second, do "pie-sharing" pricing models, such as those used in the MOSS case, make a difference in IOS success? Should the price of participation in a shared, standards-based coordination hub match expected benefits for each of the participants? Finally, what are the implications of the solution developed by MOSS for IT-enabled competitive advantage? Does the use of a shared, standards-based coordination hub imply that participants no longer achieve competitive advantage from their use of IT in their supply chains, since presumably competitors in the industry have equal access to the system and the benefits it offers? Or are competitive advantages likely to emerge despite the shared use of common IT solutions, as might be argued from the perspective of resource-based views of IT-enabled competitive advantage? These issues are raised in the second part of our discussion.

Revisiting Our Propositions in the Context of the MOSS Case

We believe that the MOSS case offers evidence in support of the six propositions presented earlier. The Industry-Wide Data and Process Standards and Adoption Proposition (P1) stated that when a supply chain IOS is based on industry-wide data and process standards, adoption by smaller and more peripheral participants is more likely. The case reveals how the availability of the standard enabled the development of low-cost software by an IT products and services vendor to the automotive industry. This software could be implemented as a client application on participants' existing systems, accessed through a simple Web browser, or (as in the MOSS case) through a shared coordination hub integrated with companies' back-end systems. The case demonstrated that pilot participants, including organizations that do business with other companies (e.g., ocean freight, 3PL companies, customs brokers), were willing to use the standards-based software. Their willingness to use the MOSS system contrasted with reactions to AutoInc's earlier, proprietary efforts that generated resistance from suppliers and other supply chain partners.

The Point-to-Point IOS and Adoption Proposition (P2) stated that point-to-point systems in a supply chain, even if based on industry-wide data and process standards, may not be widely adopted by all extended supply-chain members. Nearly all of AutoInc's past efforts at implementing IOS were point-to-point, and their history of failed efforts to incorporate smaller and more peripheral members of the supply chain into their IOS lends support to the notion that architecture is an important factor here. As prior researchers have shown, even EDI-based systems, although standards based, were not adopted by smaller and more peripheral members of the supply chain due to high costs and low incentives for adopting [8, 26, 68].

As proposed in the Point-to-Point IOS and Information Transparency Proposition (P3), the existing point-to-point IOS in AutoInc's supply chain did, in fact, lead to information transparency problems. Transparency problems were behind the errors that led to the excess supply of batteries, which was only found once the error-free data provided by MOSS was received by AutoInc. More generally, the estimated savings in shipment time and buffer inventory that resulted from the trial revealed that the existing point-to-point system had not adequately solved information transparency problems. However, the electronic provision of data to all partners simultaneously encouraged AIAG and the pilot participants to plan for reduced shipment times and lower buffer inventories, suggesting improvements in information transparency.

The Standards-Based IOS Hubs and Information Transparency Proposition (P4) stated that supply chain IOS implemented using industry-wide standards in a hub architecture would have a greater chance of solving information transparency problems. The willingness of a range of supply chain partners, including customers brokers, 3PL companies, and ocean carriers that do business with customers other than AutoInc, to participate in the MOSS pilot suggests that the industry standards-based and hub architecture of MOSS can help with adoption. It offered a glimpse at the potential for a cloud-based, SaaS solution in a supply chain context, which was well received by participants. The ability to enter the majority of the data needed by all partners just once and then have the data propagated to others without rekeying was demonstrated and associated with numerous direct savings, as well as with other planning and decision-making benefits. Other cases touched on in the review, including the ITAIDE case, lend further support to this notion.

The Private Standards-Based IOS Hubs and Adoption Proposition (P5) stated that private coordination hubs would face adoption problems among smaller, remote, and more peripheral members of the supply chain. AutoInc's prior effort at establishing a private coordination hub, as well as other cases such as Intel, did, in fact, experience adoption problems. Because private hubs are developed by a supply chain orchestrator, smaller participants that also do business with other buyers face higher costs due to the need to maintain multiple systems and procedures. This creates higher costs, and inhibits widespread adoption.

In contrast, the Shared Standards-Based IOS Hubs and Information Transparency Proposition (P6) stated that industry-wide standards-based shared coordination hubs would be more likely to solve information transparency problems. The results experienced in the MOSS pilot, which relied on a shared coordination hub integrated with back-end systems, suggest that such an IOS can attract participation from smaller and more peripheral participants in a supply chain. With greater adoption, and the information distribution advantages offered by this form of system architecture, participants experience greater information transparency and the benefits that go along with this.

The AutoInc case provides preliminary support for our theoretical framework regarding the role of industry-wide standards and IOS architecture in solving information transparency problems in complex supply chains. We recognize that it is too early to tell if MOSS will experience widespread adoption throughout the automotive industry, and so considerable follow-up study of its adoption and use is needed.

Implications for Future Research

As noted above, our case study and review of similar efforts to establish standards-based coordination hubs raises several new questions that merit some discussion. We believe these questions address fundamental issues for IOS more generally, and have direct implications for practitioners.

1. *How important are the involvement of an industry association and industry-wide participation in development of IOS solutions?*

Our review of prior research identified several examples of standards-based IOS development efforts, including RosettaNet [1, 7, 46, 54] and MISMO [49]. These examples, coupled with the MOSS experience, emphasize the critical role of industry associations in fostering the development of industry-wide standards that can be built into an IOS. They appear to suggest that it is important to have the standards-making effort organized and administered by an entity perceived by the various stakeholders to be neutral, whereas past efforts led by dominant companies created trust problems. In the MOSS case, by outsourcing the development of a standard to a neutral third party, AIAG, which represents many different interests in the industry, trust problems are mitigated; AIAG and NIST participation added legitimacy to the effort. As stated by one of the MOSS participants working for a global logistics services company:

> But at an independent company, people are not going to change their system. It has to be an industry standard. That's why if it's published by AIAG, it's an industry standard now and individual companies will subscribe to that standard. (MOSS Participant and Global Logistics Service Provider Representative)

In addition, in earlier efforts such as MISMO and ITAIDE [42], broad participation by stakeholders that represented the various segments of the value chain was deemed crucial to the development of standards that stood a good chance of adoption. MOSS standards development also involved diverse participation including logistics companies, software vendors, and manufacturers. An open question is how broad this participation in the standards effort needs to be. Is a smaller, but carefully selected committee that adequately represents the processes involved better than a larger, more inclusive group of participants in the standards development process? Prior research such as in the MISMO case enumerates the organizational benefits that accrue to both users and vendors involved in standards development. However, more research is needed to better connect the industry standards consortium approach and the structure of participation to adoption and use outcomes.

2. *Do "pie-sharing" pricing models make a significant difference in IOS success?*

One intriguing aspect of the MOSS case was the innovative pricing model used by the software vendor, where the organization that benefits the most is asked to pay for the application. It reflects a central tenet of interorganizational collaboration: that it is necessary to pay attention to the equity of costs and benefits among participants, and that successful collaborations are those that "expand the pie" of benefits and lead to greater payoffs to participants than a "go it alone" strategy [10, 31, 32, 35, 36]. This notion of equity of costs and benefits is a fundamental tenet of the literature examining collaborative approaches to IOS [24, 39, 43]. Indeed, Clemons [20] asserted more than 20 years ago that there must be strong incentives for industry trading partners before they are likely to decide to join and use a proposed system.

What appears new here is that a third-party IT services provider determined which of the participants benefited more than the others, and structured a pricing model that reflected their calculus. The participants themselves did not mutually determine how to divide up the pie, so to speak. Complex collaborative settings are characterized by numerous uncertainties such as knowledge about and expectations of resources, output, information asymmetries, intangible aspects, and other unknown factors and processes [36]. Determining how to best price the services provided in standards-based, shared collaboration hubs so that all types of participants have incentives to join will be a difficult challenge for the companies involved. More research is needed to explore various pricing approaches for achieving pie-sharing and pie-expanding outcomes.

3. *What are the implications of the solution developed by MOSS for IT-enabled competitive advantage?*

Participation in a standards-based, shared collaboration hub implies that the system is not necessarily controlled by any one of the trading partners. This creates implications for the ways in which IT-enabled competitive advantage may be achieved. Indeed, past efforts by manufacturers to require suppliers to use proprietary IOS are often understandable from a competitive advantage standpoint. From this perspective, adopting a standards-based IOS would be inferior to implementing a proprietary system since, by design, standards-based IOS are public goods [55], implying that they are available to all in the industry and one company's use does not exclude another from using them. Hence, a standards-based IOS can be implemented by competitors, negating any competitive edge that the IOS would bring to an adopting company. Even under the more cooperative approaches to supply chain management promoted in the 1990s, continued reliance on proprietary IS approaches is not irrational. For example, using a resource-based view of the firm [69], the literature on collaborative advantage and pie sharing [24, 35, 36] views the collaboration as a system that creates value that is difficult to imitate. This is because the unique combination of resources arising from the "idiosyncracies of the interfirm relationship," along with the inability of competitors to observe the system, makes imitation difficult [35, p. 463]. A proprietary IOS that is not observable by competitors would thus be more likely to provide competitive advantage than a standards-based one by this logic.

Hence, we believe that new research is needed that investigates whether and, if so, how IT-enabled competitive advantage can be achieved in a standards-based, shared collaboration hub system. Do all competitors gain equally, or does the resource-based view apply, with advantage depending on how participants leverage the complementary assets that each brings to the system [6, 67]?

Clearly, the MOSS system and other standards-based, shared collaboration hubs have provided competitive advantages to their participants. Both the AutoInc and ITAIDE cases demonstrate that exchanged business data among all relevant trading partners in long-distance supply chains enhances a trading partner's own management control. Such efforts help reduce costs and inefficiencies such as those associated with bullwhip effects. Control over business transactions may be seen as a competitive advantage for a trading partner. Achieving the status of trusted trader such as the Authorized Economic Operator (AEO) and the Customs-Trade Partnership Against Terrorism (C-TPAT) implies control of a firm's business transactions. This results in numerous benefits of accelerated trade, implying a considerable competitive advantage over a trader without such trusted trader status. However, when comparing participants at equivalent points in the value chain with each other within the systems, the factors distinguishing organizations that gain a competitive advantage from those that do not deserve more attention.

Conclusions

In this paper, we highlighted the need to improve information transparency in global supply chains. Through a review of IOS approaches that might address this problem, we argued that, in general, proprietary and point-to-point solutions are likely to fail to solve the information transparency problems in multitiered and interconnected supply chains. This is not only because of the lack of proper incentives for adopting IOS (particularly among smaller and more peripheral players) but also because point-to-point systems are plagued by delays, inefficiencies, and errors and can lead to outcomes such as the bullwhip effect. We argue that building IOS with industry-wide data and process standards can help solve the incentive problem by lowering IOS adoption costs and ensuring that participants can reuse their IT investments with multiple partners. We further proposed that IT architectures for IOS that simultaneously deliver information to all relevant partners are more likely to solve transparency problems than point-to-point systems that deliver information sequentially. Moreover, when such coordination systems are implemented in a manner that allows the system to be shared across supply chains rather than limited only to the members of one buyer's supply chain, they are more likely to be adopted as well. A key contribution of our theoretical development is the argument that these two characteristics—a data and process standard and a shared coordination hub—are both necessary. Either approach by itself will not be sufficient to overcome incentive problems and solve information transparency problems in interconnected supply chains.

We believe that the theoretical framework presented here can have far-reaching implications if supported by future research. Today, supply chains are not only becoming more global, they are also increasingly vulnerable to disruptions caused by political instability and natural disaster [28]. The recent unrest in the Middle East and the devastating effects of the earthquake and tsunami in Japan dramatically underscore such threats to global supply chains. In this context, manufacturers are likely to avoid overreliance on a small set of supply chain partners, especially if all are located in one region. These trends suggest that the kind of supply chain IOS described here would be of great utility. If there is a need to rapidly reconfigure a supply chain that has been disrupted, our framework describes an IOS approach that can be easily adopted by new partners, including smaller and more peripheral ones. Moreover, manufacturers seeking to become less vulnerable to disruption will require an IOS approach similar to the one we described here.

Our case study of the MOSS project provides preliminary evidence that the standards plus shared hub approach can address the information transparency problems in interconnected supply chains. In addition, the case raises new research questions regarding the role of standards bodies, the nature of pricing, and the effects on competitive advantage. Future research is needed to answer these new questions and to test the validity of the standards plus shared hub approach in other conditions and contexts.

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Note

1. NEHEN field research notes, available from the authors upon request.

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