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DECISION SUPPORT AND SYSTEMS INTEROPERABILITY IN GLOBAL BUSINESS MANAGEMENT

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ABSTRACT

Globalization of business and volatility of financial markets has catapulted ‘cycle-time’ as a key indicator of operational efficiency in business processes. Systems automation holds the promise to augment the ability of business and healthcare networks to rapidly adapt to changes or respond, with minimal human intervention, under ideal conditions. Currently, system of systems (SOS) or organization of networks contribute minimally in making decisions because collaboration remains elusive due the challenges of complexity. Convergence and maturity of research offers the potential for a paradigm shift in interoperability. This paper explores some of these trends and related technologies. Irrespective of the characteristics of information systems, the development of various industry-contributed ontologies for knowledge and decision layers, may spur self-organizing SOS to increase the ability to sense and respond. Profitability from pervasive use of ontological frameworks and agent-based modeling may depend on the ability to use them through better enterprise and extraprise exchange.

Keywords: Systems, Interoperability, Supply Chain Management, Semantic Web, Agent Systems, Ontology, Unique Identification

1. INTRODUCTION

The ability to connect atoms (physical objects, goods, humans) with bits (data about objects or process) may be described as the Holy Grail of creating a real-time world model where data or information about objects or goods or humans are accessible on demand, anytime, anywhere. Diverse practices, such as healthcare and supply chain management (SCM) [7], may be viewed as a subset of this over-arching concept of connecting bits to atoms. Real-world supply chains involve the flow of goods (atoms) and data (bits), in various combinations. A more descriptive version may characterize the supply chain as a network of players that transforms raw materials into distributed products and services. Network of supply chain partners may share processes, data and information through various stages over an extended time frame. These partners are members of a value chain network. Obvious benefits of such collaborative principles were business drivers for the pioneering entrepreneurs of the 1990’s who created a variety of e-marketplaces. The demise of several e-markets (for example, SAP Markets) may be rooted in lack of systems interoperability and trust. However, the core principles of e-markets are still viable. This paper refers to them, in a generic sense, as community systems or system of systems (SOS) that may promote sharing of supply chain information and process knowledge by virtue of being positioned as a subset of an information hub or part of a greater network that may be connected through intelligent data agents to the ubiquitous data bus. SOS may be broadly divided into (a) business to business collaborations, such as, RosettaNet and (b) systems used for regulatory compliance and security, such as customs. These systems of systems may act as hubs through which partners of value networks may share time-critical information in largely event driven, asynchronous modes.

Business processes are multi-stage and interdependent [4]. The nature of collaboration implicit in these processes appears to suggest that supply chains actually compete with one another rather than individual business [19]. Few, if any, centralized supply chains exist where decision making is a shared or collaborative command and control operation between partners. Generally, decisions are made by value network partners, aiming to maximize their own profitability. Such decisions are autonomous, spatially and temporally distributed, layered and heterogeneous. However, the gradual dissemination of the virtues of vendor managed inventory (VMI) or collaborative planning, forecasting and replenishment (CPFR) [3, 6], are triggering some forward thinking businesses to explore sharing some data and/or information with supply chain partners, albeit selectively. To profit from globalization, it is necessary for such collaborative practices and data sharing to occur in endemic proportions if global supply chains wish to respond or adapt to supply-demand fluctuations, often driven by outlier events in far corners of the world.

Evolution of information systems to serve supply chain processes is extensively documented. Electronic Data Interchange (EDI), now considered archaic on a technological time scale, is one such medium for inter-enterprise information exchange. Intra-enterprise exchanges are expected to augment the resource view to enable enterprise resource optimization, as claimed by the proponents of early enterprise resource planning (ERP) system developers [16]. Off-the-shelf SCM systems are built to fit ERP systems but they often lack functional integration because planning, optimization and execution still are largely disconnected. One reason for the disconnection is that the decision space, in strategic supply chain planning and execution, is plagued with inadequate analytical tools and often lack real-time information. In addition, SCM systems are positioned for decision support within the four walls of the organization (local optimization) but profitability in a highly competitive global economy must respond in near real-time to the challenges of complexity presented by global optimization [1]

This paper explores supply chains issues that may benefit from innovation in inter- and intra-enterprise interoperability. Further, this study reviews how some of the existing technologies (agents and ontology) may help deliver some beneficial solutions in this space. Finally, this paper addresses the elusive quest for identification of information that enables systems interoperability through convergence [10].

2. OPPORTUNITY LANDSCAPE

2.1 Supply Chain Management

Profitable supply chain strategies must remain attentive to the dynamic interplay of adaptability and efficiency in order to balance product-centricity versus the consumer's demand for choices with respect to variables such as cost, quality, service and cycle-time [20, 22]. A key strategic domain is the creation of a robust yet flexible supply network plan (suppliers, production facilities, distribution centers, warehouses) with adequate options for *ad hoc* and/or planned redundancies to mitigate risk in the global business environment [12, 13]. Another crucial domain involves logistics (sources, sinks, centralized vs decentralized, direct shipment, cross-docking, pull vs push, transportation, e-manifest, tracking, traceability). The quantitative decision domain involves determination of quantity and location of inventory including raw materials, work-in-process (WIP) and finished goods. SCM information systems generally revolve around these decision domains. Efficiencies and profitability may depend on the extent to which systems and processes of the supply chain are enabled to share real-time information about demand, forecasts, inventory and transportation (all of which have a bearing on the above decision space).

Of interest in this space is the bullwhip effect reflecting demand volatility or amplification in supply chain domains [15, 21]. For example, small changes in consumer demand at retailers may cause large variations in the inventory at distributors or manufacturers. Thus, near-real time information about small changes along the chain must be accounted in supply chain models. Technologies, such as radio frequency identification (RFID), may be useful for acquisition of inventory data at the item level if there is sufficient business value for such granularity of data and if the data can be used to generate information that can lead to decisionable action or transaction.

2.2 Regulatory Role

Supply chain facilitation offers opportunities for businesses to optimize profitability. For government agencies such as customs and border security administrations, the concerns are different. Availability of real-time accurate data, in advance, is one key element in their effort to target high risk shipments or assess threat. Operational profiling (source of goods, personnel, routing) is an emerging paradigm for decision support systems that deal with threat assessment and risk management.

This problem space in the regulatory domain is in sharp contrast to the facile view of information systems in business supply chains. Globalization has forced supply chains to span multiple geographies and introduced a significant regulatory step for all physical objects and goods that cross geographic boundaries. This intersection of facilitation versus regulation falls squarely in the operational domain of customs administrations in each country [25]. Supply chains involve actual shipment of good across boundaries. The efficiency with which these goods are handled (shipment, receipt, distribution) is critical because delays will impact inventory (risk of out-of-stocks), quality of services (QoS), cycle-time, cash cycle, capital costs and transportation. It appears, therefore, the tax collectors of customs must evolve from the revenue domain to become an integrated part of the global supply chain if countries want to remain competitive in a global economy without business borders, at least in theory. The issue of interoperability is crucial and global organizations must view interoperability with a far more inclusive vision.

3. MULTI-AGENT SYSTMES

3.1 Evolution of Agents

Agents as automated software entities have been under development and use since 1960's. In the early days 'daemons' written in primitive UNIX could be fashioned as perpetually operating background processes. Agent technologies are currently used in remote management of IT infrastructure. Autonomous software agents monitor the health of infrastructure components, such as simple network management protocol (SNMP), or are evoked in simple processes such as remote procedure call (RPC). This is an example of master-agent communication where the master delegates responsibility to autonomous agents for real-time sensing and reporting (to master). It was demonstrated that given proper task decomposition, agents could collaborate to provide coordinated output that would make sense to human users through the master controller.

Agent technologies are evolving to include agent-to-agent (peer-to-peer) relationships communicating over mesh networks without master controller. These agents may have spatial mobility on the network (mobile agents migrating computing power closer to the data) and may have computing capabilities with rudimentary intelligence (using fuzzy algorithms, neural nets and methods that emulate machine learning). Industrial grade agents could be reliable, robust and fault-tolerant. Role-differentiated collection of agents may collaborate to act as intelligent multi-agent system. Such a group or swarm of agents (or agencies) will collectively exhibit emergent behavior different from individual agents (swarm intelligence).

3.2 Structure of Agents

Traditionally, agent software may have five conceptual layers [5]. The outer envelope, generally, is the Communication Layer (for communicating with other agents). The Interface Layer is for sensing and effecting. In between the communication and interface layer is the computational payload, comprising the Definition Layer (that makes the connection with the Interface Layer). The Organizing Layer is usually responsible for core processing of information in conjunction with the Co-ordination layer which handles inter-agent inputs.

Sycara [24] lists the characteristics of multi-agent systems as collectively autonomous, but task-specific and inter-dependent, systems that sense, seek and process information in their respective problem domains. In each problem domain there could be many deployment strategies for multi-agent systems. Researchers have explored some of the uses of agent technology in SCM [26] but there is much room for improvement based on bio-inspired mechanisms.

3.3 Use Case: Track and Trace Agent

Profitability and security are both equally powerful drivers for access to real-time data and information about inbound and outbound consignments all the way from the original consignor to the ultimate consignee. In order to make this a reality, it is increasingly necessary to take advantage of automatic identification technologies and the devices (sensors, RFID tags, GPS) that may be placed on goods, carriers and fixed locations, such as, entry, transit and exit points in factories, warehouses, ports and public places. Embedded agents in the software layer may contain business logic (facilitation of supply chains for profitability) and/or risk profiles (regulation of supply chains for security) to continually monitor and/or analyze.

A typical use case involves sending RFID or sensor data (translated into information) to a data receptacle or UDB or business application or secured access key such as the unique consignment reference (UCR). Location awareness of objects is an over-arching theme in this physical world model where bits are not only connected to atoms but bits are also connected to bits [10]. Progressive adoption of automatic identification tools (for example, RFID) makes location awareness possible but the value of such data may not be realized without advances in context aware applications and mechanism to innumerate information [9]. For example, use of such information may help prevent accidents if cross-reactive chemicals were being transported in containers. Information agents and message filtering agents can route context-aware object status either to automated decision systems or induce human intervention.

4. SEMATIC WEB

4.1 Core Principles and Ontology

The vision of the semantic web, first formally outlined by Tim Berners-Lee in 1995, has matured [2]. Progress has taken place in research communities around the world to demonstrate that semantic web offers the potential to address some of today's problems. Semantics is a collection of resource description framework (RDF) data (or any other semantic language) which describes the meaning of data through links to ontologies, which act as decentralized vocabularies. Ontology is a term borrowed from natural philosophy. Therefore, a definition of ontology may state that ontology is a theory about the nature of existence (of what types of things exist). Artificial intelligence and semantic web researchers have co-opted this term to indicate a document or file that formally defines the relations among terms. Computers in future, empowered with this metadata, may be far more meaningful and contextual in their understanding of the data without human intervention, provided that the data is in machine readable format [2]. The latter is a problem that may have to seek an entirely different solution [10]. Human language thrives when using the same term to mean somewhat different things, but automation does not. Dertouzos [14] and Hendler [18] explain this central issue with a brilliant and simple example.

The real power of the semantic web will be realized when agents collect web content from diverse sources (for example, stock quotes from Bloomberg or microarray data), process the information (for example, in relation to your business or diagnostic test) and exchange the results with other programs or data (for example, demographic data or metabolomics index). The effectiveness of such agent based activities will increase exponentially as machine-readable web contents, automated information services and real time-data become available. The semantic web promotes the synergy between agents that were not expressly designed to work together but can now transfer data among themselves if data is marked-up with semantic tags that can be identified, uniquely.

There may not be any one standard ontological format even for very closely related topics because the same format can be framed differently in a different language. Hence, the need for numerical relations [10]. But at present, for the semantic web to be useful it will be necessary to have layer(s) of mapping functions (analogous to adaptors and transformers that are necessary to use electrical appliances across geographic boundaries). Advanced applications will use ontologies to relate the information on a page to the associated knowledge structures and inference rules. This mark-up makes it easier to develop programs that can tackle complicated questions whose answers do not reside on a single web page yet vital for certain users, for example, in healthcare. Access to these pages or data will demand security and authentication. Therefore, for agents to accomplish tasks that require data or information from multiple sources, an important facet of agent function will be exchange of proofs which may be written in the semantic web's unifying language using rules and information such as those specified by ontologies, as shown in Figure 1. Some programs claim to exchange proofs in this way, using the preliminary versions of the unifying language but they are far from plumbing the depths of the semantic web's true unifying potential.

Present day discovery engines and automated web services claim to discover and connect to various services. It is doubtful if at present the agents have found a way to locate a service that will perform a specific function. This process, that is, true service discovery, may happen only when there is a common language to describe a service in a way that enables other agents to understand both the function offered and how to take advantage of it. Services and agents can advertise or publish their function by depositing such descriptions in directories (Ontology Yellow Pages). Some low-level service-discovery schemes, such as Microsoft's Universal Plug & Play, focus on connecting different types of devices (information box in Windows XP: Found New Hardware). These initiatives, however, attack the problem at a structural or syntactic level and rely heavily on standardization of a predetermined set of functionality descriptions. Standardization can only go so far because it is difficult to anticipate future needs and disruptive changes.

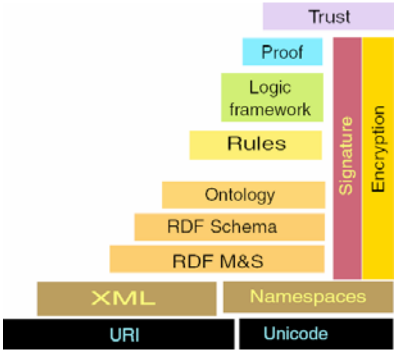

Figure 1: Semantic web layers from [2].

One antidote to standardization and n:m relationships is semantics. The semantic web is flexible and in the future may be made even more useful [10]. Consumer and producer agents can reach a shared understanding by exchanging ontologies, which provide the vocabulary needed for discussion. Agents can learn new reasoning capabilities when they discover new ontologies. Semantics makes it easier to take advantage of a service that may only partially match a request. A typical process involves the creation of a value chain in which sub-assemblies of information are passed from one agent to another, each one adding value to construct the final product requested by user. To create complicated value chains, automatically, on demand, agents may increasingly exploit artificial intelligence techniques including tools from swarm intelligence, such as, ant-based algorithms. Semantic web has its potential to provide the foundation and framework to make such technologies more feasible. Its use may become ubiquitous and pervasive as context-dependent communication evolves successfully and deftly to address the many idiosyncrasies of the human language-dependent ontological frameworks through intelligent mapping functions and unique numerical relationships among them [10].

4.2 Decision Support

The semantic web may be envisioned as an evolutionary improvement of the syntactic web [2] that is capable of understanding the meaning and by extension, eventually, the context, of information. In practice, the tools of the semantic evolution may enable software applications to read information presented on the web as easily as humans read web pages, process information contained therein and arrive at useful outputs in order to display meaningful information for other software applications or humans to use or act upon. Thus, a web of data, information and process silos can be linked depending on the contextual relationship between the data or process. Ontologies and the semantic web may enable this contextual relationship to be recognized but the semantic web, *per se*, does not link the data silos or process streams. One way for such connectivity to occur is through the use of agents that can now search and find the necessary data or process because of a common language (ontology) that delivers the meaning (semantics) of the data or process, which in turn can bind together to generate useful information that may trigger an improved decision making process (not possible in the syntactic web framework where the meaning of the data or process cannot be read by other systems or agents).

The ability of the semantic web to be increasingly functional and productive for use by non-experts depends on the underlying growth of ontologies and ontological frameworks that can be uniquely identified. It is the latter that makes “machine readability” of data and “meaning” a part of the function that is expected to be delivered through the semantic web. One rate limiting function in the diffusion of the semantic web is the growth of the ontologies or at the next deeper level, the mapping and innumeration between ontological frameworks. For example, ontologies contributed by the Japanese and German auto manufacturers may differ but through mapping transformations (that are also uniquely identifiable) the differences may be opaque for a potential consumer who is comparing automobiles irrespective of their ethnicity. The ontological frameworks are also keys for agents to understand process relevance and for ability of discovery or search services (Web X.0 or true web services of the future) to link context of data, process or services within or between entities. For example, the business process, purchase order in one company, is business-relevant to invoice in another company based on the assumption that if Apple wants to buy Intel microprocessors then Apple will issue a purchase order and Intel will issue an invoice requesting payment from Apple.

Currently, in the syntactic web the method is to use by directories peddled by consortiums such as ebXML Registry, RosettaNET (PIPs) and UNEDIFACT, to name a few. These directories are very useful when only a few partners are involved in a generally stable industry but globalization has shredded such norms. Validating and maintaining these directories is inefficient and will generate problems as process descriptions multiply in the multiple languages involved in business operations that characterize global supply chains. In the semantic context, no matter how the descriptions vary or evolve with globalization, the meaning that is relevant to the process remains understandable (hence, machine readable) based on contributed ontological frameworks or mapping between ontological frameworks and especially if the framework offers a mechanism for unique identification [10]. The semantic web still holds the promise of interoperability (and value) that is hitherto unimaginable in a syntactic world. The convergence of unique identification of information and the semantic web with agents capable of accessing real-time data and right-time analytics is a step toward intelligent interoperable decision systems.

5. USE CASE: GLOBALIZATION

5.1 Global Business Traffic Across Geographic Borders

Globalization has forced cultural amalgam that depends on efficacy of change management to reap the benefits. Fueled by resistance and paranoia, changes to embrace or accommodate globalization are few and far between in global business and financial markets. Drivers of change management are amorphous and differences in policy, standards, trust and financial inequalities create further hindrance. Governments, organizations and businesses are exposed to these changes without adequate training, tools or frameworks to enable them to deal with global commerce. Regulatory compliance may be often divorced from business needs and decisions may be made based on inaccurate or corrupt data. Processing of data to yield valuable actionable information remains largely unexplored and is often plagued by lack of visibility due to inconsistent interoperability. These problems are compounded by the inability of systems to adapt or respond in near-real time despite the advances in technology and progress toward intelligent decision systems.

Interoperability between systems and adequate operational transparency may help stem some of the frustration of businesses unable to fully enjoy the fruits of globalization, for example, outsourcing or offshoring. On the other hand, regulatory agencies must remain vigilant to ensure security through tracking and tracing of goods to prevent disenfranchised individuals from taking advantage of the movement of objects between geographic boundaries. Therefore, tracking data for a sealed container from the Port of Hong Kong must be visible in systems of different countries while the container is at sea or if the vessel makes stops *en route* before arriving at its final destination. Transmitting the data to a list of systems level addresses is not possible with the current system of data routing and using alphanumeric numbering schemes such as UCR, electronic product code (EPC), global trade identification number (GUID) but may be possible in the near future [10]. Currently, the occurrence of black holes of information is expected due to operational and/or technical inadequacies between systems. The integrity of the physical seal of the container and its location is as important as the identity and source of the goods. While efforts are underway to optimize secure container shipments, the operations are often at the mercy of the local logistics providers who may horde the data about the source and identity of goods. Ideally, goods must be traced further back into the business supply chain to ensure credibility of the source. At present, visibility of the chain is quite restricted if not completely unavailable and the ability to uniquely identify information still does not exist [10].

There are no easy "one shoe fits all" solutions to these problems and the author's proposal [10] may not be a panacea of a solution 9, either. There is also room for debate as to whether the depth of collaborative visibility of the supply chain can be turned into a profitable advantage rather than compromise true competition. The investment necessary to gain visibility and transparency both in terms of cost as well as change management can only flourish if it is a collaborative venture that includes regulatory agencies, such as, customs and border protection agencies. All parties must be equally determined to remain cognizant about operational efficiency. However, even for pre-agreed issues, the ability to generate a bird's eye view of the sequence of processes is plagued by the lack of interoperability between customs and business systems. Shared data models, common process descriptions (ebXML Registry) and alphanumeric serialization attempts (EPC) are aimed to offer some degree of standardization but extremely limited in their ability [9, 10]. It follows that any attempt at standardization requires sufficient adoption of the so-called standards in order to harvest the anticipated efficiencies from economies of scale of adoption.

The unrelenting emphasis on the need for interoperability may evoke the thinking that using the same software serves as infrastructure to ensure communication and interoperability between systems. It is true that the latter may be one way to reduce uncertainty but it is certainly not a reasonable *modus operandi* nor can any specific software be recommended. The diffusion of the semantic web may facilitate adaptable interoperability between systems without the need for elimination of heterogeneity of systems based on numerical relationships.

In the world of the syntactic web, interoperability is possible but at a higher cost of maintenance. The ability to connect between unrelated systems through the use of connectors that may use (adopt) one or more standards, formats or frameworks, specified by groups or associations, may offer functional interoperability that may serve useful purposes. For widespread use, connectors must be rapidly implemental, capable of data or information exchange, preferably possess some intelligence or analytics and must be easy to upgrade but remain adaptable.

The adaptability part of the adaptable interoperability paradigm refers to processes that are used in a variety of operations. If the processes remain unique then businesses will incur a high cost to interact, globally. If the processes are rigid then changes will be slow and painful. Because, nations are unlikely to agree on any one new process map and its financial manifestations, it is imperative that process descriptions must entertain diversity with the greatest design flexibility to rapidly adapt to change or use a pre-agreed standard domain approved for global adoption [10]. In the syntactic web, interoperability may be accelerated if processes are designed in a manner that can be easily translated in terms of the semantic content even though the syntax of words in the description may vary between operations. For example, ports in one country may specify "containers per vessel" while the same process may be described as "unit containers in each cargo ship" by another port system. In the semantic sense they are identical but the syntax is sufficiently different to create barriers for interoperability between two software systems hard-coded to one process or the other. It is for this reason a further numerical relationship may be necessary in the future [10].

The technical issues cryptic in the above example may find some similarities with human language. Translation from English into French can be achieved by the brain of the translator. It is equivalent to (in this case) the software in the system that extracts the semantic context from the syntactic description of the process (without interruption or human intervention) to execute the desired functionality.

Current software systems offer a limited number of descriptions and few analytical tools in order to maintain system complexity at a manageable level. These systems use 1:1 links, require expensive resources and often call for re-programming since they are based on fixed processes. The US Government Accountability Office predicts in a recent report that US Department of Defense may have spent nearly $14 billion on software changes in 2006 (Federal Computer Week, 31 July 2006). The latter are detrimental to the economy as a whole and in particular to the dynamic necessity of process change. It stands to reason, that adaptable interoperability is essentially a culmination of meaningful convergences that offers the potential to catalyze innovative solutions. This scenario is not an IT development. This is a fundamental advance in the ability of science to foster machine intelligence which is built, in this case, on the evolution toward the open source technology of the semantic web, provided data and processes are machine readable. Semantic systems are emerging and may be implemented without any new discoveries but using a different set of numerical relationships [10].

5.2 Port Systems

Supply chains involving goods transported via land, air and sea often suffer from uncertainty in cycle time when port authorities or regulatory intermediaries must issue clearance before the goods can flow back in the business operation and enable financial transactions. Therefore, ports are major institutions and a key node in the order fulfillment cycle as well as the bill to cash cycle.

The word "port" is an amphibole of different meanings - an aggregation of commercial enterprises seeking profits and operating a natural monopoly in providing a public utility service. On the ocean side, the port serves the vessels represented by shipping agent and non-vessel operating common carrier (NVOCC). In addition to cargo carrying vessels, there are port-based service providers such as tugs, pilot vessels and lighters. On the harbor side, there are terminal operators for facilities at wharves and berths for handling cargo, storage and warehouse facilities that serve inside and outside the customs bonded area. Port Authority (handling traffic and commercial operations), Customs and several government departments (Public Health, Transport and Security) have a presence at ports. The primary consumers of port services are the businesses and organizations involved with storage and movement of goods. These include stevedores, road and rail transport forwarders, warehouse operators, container terminal operators, storage providers, container repair operations and the various branches of Customs.

These organizations are involved in a complex web of interdependent relationships and conduct a great deal of intra-community business. The underlying element of this business is the sharing of information concerning cargo and logistics. Information related to payments, transactions and consignments are exchanged between these entities using a wide variety of different business systems and processes, databases and methods of exchange. The flow of data and information is expected, theoretically, to stay ahead of the flow of goods but in practice this is the key problem associated with port management [17]. Typically, cargo movement is a 2-part operation: (i) movement of cargo between the ship and the gate of the terminal, depot or wharf, and (ii) movement of cargo between the customer (shipper/consignee) and the gate of the terminal, depot or wharf. These segments may be sub-divided into steps or processes that include harbor entry (reporting the ship, arrival of ship, berthing), loading/unloading cargo, harbor exit (clearing the ship, departure), cargo clearance involving importer, customs, NVOCC (containers), cargo consignment involving road transport and inland haulage.

Integration of operational data flow between the different entities in a port is a key to efficiency and security. Partners must have secured access to relevant data and systems to process transactions. The core services are equipment availability, delivery requirements, demurrage information, bookings, bills of lading, vessel, barge and rail manifests, load and discharge lists, vessel schedules, export receipts, work schedules, empty container returns, transfer between container freight stations and inland container depots, regulatory holds and permits and payment for port services (permits, release, customs clearance). Delivery is the successful outcome of these processes that must operate in synchrony and largely driven by documentation and information.

On the other end of the spectrum, between the feasible and fantastic, in the context of community systems or SOS in port operations, is the goal of real-time process visibility in a paperless environment. The 'paperless port' is a cliché. But somewhere in between, a couple successful examples are worth citing. The Felixstowe Community System is a port community system that covers over 80% of container cargo moving in and out of UK. NACCS in Japan is an example of a port community, where major participants have dedicated relationships with one system (operating for customs). Port systems must view the writing on the wall and prepare for stringent risk management that security concerns demand. Systems interoperability and real-time access to accurate data and status will be pivotal in any assessment of threat. Soon, port systems may be required to respond to the scenario outlined in the illustration (Figure 2) below and strategies such as non-obvious relationship analysis (NORA) may become an integral part of port security analytics.

The intersection of policy, rights and suggestive clues when combined with investigation, offers a very complex scenario. Policy and rights must be evaluated by law enforcement prior to any action, exploratory or investigative. For example, there exists a possibility of a mandate by the US in the form of Customs-Trade Partnership Against Terrorism (C-TPAT), as shown in Figure 2. Only Tier 3 certified companies may be allowed by US Customs to receive clearance without or with minimal inspection of their containers. To qualify for C-TPAT Tier 3 certification by US Customs, business must share data through the Advanced Trade Data Initiative (ATDI). Sharing sensitive data will add layers of data security. With data from ATDI, the customs enterprise system or Automated Commercial Environment (ACE) is expected to run analysis to spot anomalies, integrate biometric information (individuals, meat and agricultural products), perform non-obvious relationship analysis (NORA), assess threat and forecast risk profile associated with containers. Armed with this information, customs aims to selectively target cargo for inspections. A mere 60-day delay in customs clearance cost US businesses $58 billions in supply chain losses [25].

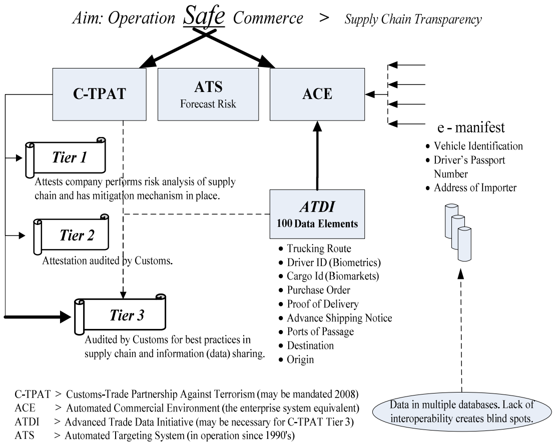

Figure 2: Port security related pilot projects in the US.

5.3 Agents in Port Systems

Ports are, therefore, a "cog in the wheel" of globalization and the global goods supply chain as well as the financial supply chain. Ports must bear the dual responsibility for trade facilitation and a prominent role in security regulation. Port community systems contain the necessary tools and infrastructure entrusted to execute these dual functions which are on opposite ends of the spectrum. The diversity of sources of data and information may make it impossible to thread together a multiplicity of systems (SOS) and orchestrate systems level maintenance to continually synchronize real-time data, updates and changes, to be equally effective in facilitation and regulation.

Traditional systems demand harmonization and applications insist that data is derived from one central source which is expected to be accurate as well as authentic. This is antithetical to the multi-agent systems that thrive on data from multiple sources. Agent systems bring the program to the data and not vice versa (as is the case in traditional systems). Agent systems do not depend on data replication or synchronization techniques to maintain databases. Therefore, it is difficult to understand how efforts like Global Data Synchronization by EPC Global aims to deliver the benefits of 'intelligent' globalization if Agent based models were integrated with software as infrastructure for SOS.

The enthusiasm in the industry for Service Oriented Architecture (SOA) may be justified because it may be a catalyst for enterprise-wide and inter-enterprise collaboration and integration. Illustrated in Figure 3, SOA appears to offer choices to deal with complexities and the future [23]. However, there are only a few implementations to date since the technology and its plethora of advantages are poorly understood by practitioners, especially in public utility monopolies (such as, ports). In addition, public institutions are refractory to change and may continue to struggle to stay within their comfort zone with entrenched legacy systems rather than embrace new solutions.

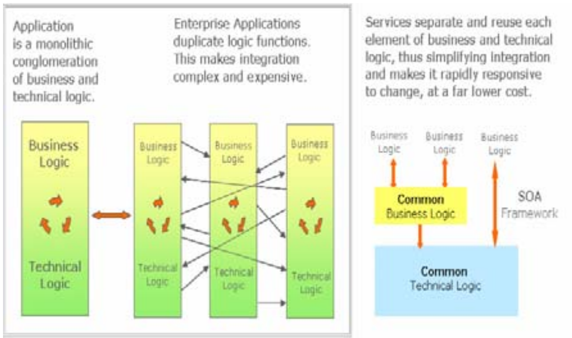

Figure 3: SOA framework's role in the enterprise-wide and inter-enterprise collaboration and integration.

6. CONVERGENCE

6.1 Sensors

The separation of business logic (process) from technical logic (device) outlined above in the discussion on SOA may be a key to harness value from ubiquitous computing. The nature of ubiquitous computing is still largely unknown but growth of wireless sensor networks may be an emerging example of pervasive ubiquitous computing. Application of sensors span the entire gamut that includes sensing of blood pressure and transmitting them to monitoring devices or to suggest trends of warehouse shelf occupancy or smell hydrogen leaks in future hydrogen cars. Sensors do not transmit identification data, such as EPC or GTIN, characteristic of auto-id technologies. Sensor data, therefore, cannot be used in the same manner as RFID generated EPC. Sensors cannot be plugged-in directly as internet devices (InterDev) unless IPv6 (internet protocol version 6) is in use or the TCP/IP stack is subjected to architectural redesign with the much anticipated security layer (in progress).

Figure 4 illustrated how sensors are self-powered devices and form mobile wireless *ad hoc* networks (MANET) that upload through specific nodes which may be then connected to data stores or the internet. Each sensor may have certain analytical abilities and due to in-network processing, some sensor networks transmit analyses of the data rather than the raw bits of data to provide answers instead of only numbers to the system. Sensor data may require different thinking in terms of adaptive flow or streaming databases. The data (analyses from sensor nodes) may stream through databases where the query is stored. For example, light emitting sensor network in a secure room sends positive light emission data on which the query (is anybody entering the room) need not act. Only when an obstruction causes a break in the network or occludes the light from a sensor, then, the query comes into effect and is answered.

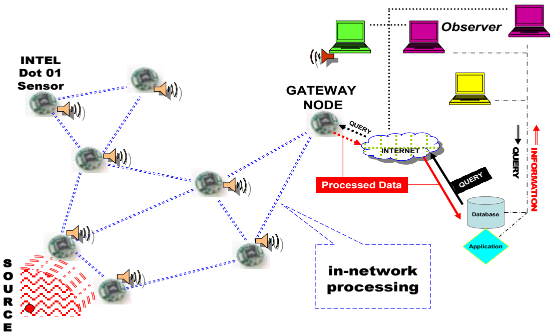

Figure 4: Sensor on the wireless *ad hoc* networks.

Embedded sensors are likely to influence fields as diverse as healthcare and supply chain [11]. Sensors attached to spindles in drilling machines may upload the status of the spindle in order that it is serviced or replaced within a reasonable time to avoid breakdown and downtime. Metrics, for example, meantime between failure (MTBF) and other parameters may be helpful to schedule preventive maintenance. Service supply chains (such as heating, cooling) may benefit from sensor-linked monitoring to determine when to send technicians to stem problems before they require emergency attention. The key is to integrate sensor data to improve performance. The flood of data from nanosensors may require agent integrated systems to extract intelligent information. Bio-nanosensors may evolve as an influential component of healthcare services and management.

7. CONCLUDING COMMENTS

Development of ontologies that represent the knowledge of the problem space may facilitate use of agent systems within the semantic web infrastructure. Supply chain operations involving buyers and sellers separated by geography and political boundaries must waddle through a host of process intermediaries (finance, logistics, compliance, security) yet reduce cycle times to boost efficiency and hence profitability. New approaches, especially the emergence of unified identification [9, 10], web services and SOA, taken together with agents and the semantic web offers opportunities for interoperability in business, finance, healthcare and security.

In addition to the topics discussed in this paper, the need for SOS interoperability permeates throughout daily usage and common observations 8. Therefore, from a broader perspective, a reasonable confluence of these and existing concepts, tools, technologies and standards may collectively, improve adaptability of systems with little or no human intervention. It may even impart some degree of intelligence to decision systems to combat uncertainty or improve event-driven applications as diverse as profit optimization, response time in healthcare or hospitals [7], military readiness, emergency planning and detection of potential security threats or risks. To expedite the pace of improvements, an introspective look, at the issue of process illiteracy of technologists and the technical illiteracy of process specialists, may be warranted. Among other things, this paper has also made an attempt, albeit feeble, to offer such a bridging function, as well, by oscillating between process discussions and advances in technology, viewed with the general perspective of offering real-world solutions.

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REFERENCES

1. M. Ahmed, "Meeting the challenge of complexity", *The 47th Annual Power Industries (POWID) Conference and the 14th Annual Joint POWID/EPRI Controls and Instrumentation Conference* (2004).
2. T. Berners-Lee, Semantic web road map, http://www.w3.org/DesignIssues/Semantic.html (1998).
3. M. Caridi, R. Cigolini and D. D. Marco, "Improving supply-chain collaboration by linking intelligent agents to CPFR," *International Journal of Production Research*, **43(20)**, 4191-4218 (2005).
4. S. Chopra and P. Meindl, *Supply Chain Management: Strategy, Planning and Operations*, Prentice Hall, Upper Saddle River, NJ (2001).
5. J. Collis and D. Ndumu, ZEUS technical manual: the ZEUS agent building toolkit, Intelligent Systems Research Group, BT Labs (1999).

6. P. Danese, "Collaboration forms, information and communication technologies, and coordination mechanisms in CPFR," *International Journal of Production Research*, **44(16)**, 3207-3226 (2006).
7. S. Datta, Adapting decisions, optimizing facts, predicting figures Working paper, Engineering Systems Division, MIT (2004).
8. S. Datta, "Charlie's Skypeout strategy: the chocolate factory relocates to Tallinn," *TEKES Technology Review*, **196**, 41-52 (Published by TEKES Government of Finland, Funding Agency for Technology and Innovation, Helsinki. http://www.tekes.fi/julkaisut/E_Business.pdf) (2006).
9. S. Datta, Answers, not numbers: information solutions for distributed decision systems, (In preparation) (2007).
10. S. Datta, Unified theory of relativistic identification of information: convergence of unique identification with syntax and semantics through internet protocol version 6 (IPv6), Working Paper (submitted), http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf, Engineering Systems Division, MIT. IOT 2008, Lecture Notes in Computer Science, Springer-Verlag (in press) (2007).
11. S. Datta, B. Betts, M. Dinning, F. Erhun, T. Gibbs, P. Keskinocak, H. Li, M. Li and M. Samuels, *Adaptive Value Networks (Chapter One in Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks and ICT (Information Communication Technology)*, Kluwer Academic Publishers, Amsterdam (2004).
12. S. Datta and C. W. J. Granger, Advances in SCM: improving forecasting accuracy, Working paper, http://esd.mit.edu/WPS/esd-wp-2006-11.pdf, Engineering Systems Division, MIT (2006).
13. S. Datta, C. W. J. Granger, M. Barari and T. Gibbs, "Management of supply chain: an alternative modelling technique for forecasting," *Journal of the Operational Research Society*, http://www.palgrave-journals.com/jors/journal/vaop/ncurrent/abs/2602419a.html#aff4 (2007).
14. M. L. Dertouzos, *The Unfinished Revolution: Human-centered Computers and What They Can Do for Us*, Harper Collins, New York, NY (2001).
15. S. M. Disney, M. M. Naim and A. Potter, "Assessing the impact of e-business on supply chain dynamics," *International Journal of Production Economics*, **89(2)**, 109-118 (2004).
16. T. W. Ferratt, S. Ahire and P. De, "Achieving success in large projects: Implications from a study of ERP implementations," *Interfaces*, **36(5)**, 458-469 (2006).
17. S. W. Hakim, G. W. Bowman and P. Seidenstat, "*Privatizing Transportation Systems*", Praeger, Westport, CT (1996).
18. J. A. Hendler, Tetherless world senior constellation professor, Rensselaer Polytechnic Institute (RPI), Troy, NY**,** Personal communication: http://www.cs.rpi.edu/~hendler/.
19. R. Kalakota and M. Robinson, *e-Business 2.0: Roadmap for Success*, Addison-Wesley, Boston, MA (2001).
20. H. Kotzab and A. Otto, "General process-oriented management principles to manage supply chains: theoretical identification and discussion," *Business Process Management Journal*, **10(3)**, 336-349 (2004).
21. H. L. Lee, V. Padmanabhan and S. Whang, "The bullwhip effect in supply chains," *Sloan Management Review*, **38(3)**, 93-102 (1997).
22. R. R. Lummus and R. J. Vokurka, "Defining supply chain management: a historical perspective and practical guidelines," *Industrial Management & Data Systems*, **99(1)**, 11-17 (1999).
23. A. Mulholland, C. S. Thomas, P. Kurchina and D. Woods, *Mashup Corporations: The End of Business as Usual*, Evolved Technologist Press (2006).
24. K. P. Sycara, "Multiagent systems," *AI Magazine*, **19(2)**, 79-92 (1998).
25. B. Worthen, "Security compliance - customs rattles the supply chain", *CIO Magazine*, March (2006).
26. Y. Yufei, T. P. Liang and J. J. Zhang, Using agent technology to support SCM, Working paper (2005).