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The Internet of Things as an Enabler to Supply Chain Innovation

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***Abstract*—The Internet of Things (IoT) connects physical-world to the cyber-world, which may impose predicable and unpredictable changes to enterprise business models and our everyday life. In this paper, we propose a model to describe the impact of IoT on the material, information and capital flow as well as carbon footprint through the supply chain, and further support the model with possible business scenarios. Besides, we raise several issues that may interest scholars and practitioners.**

Keywords-Internet of things; supply chain; business scenarios;

I. FROM RFID TO THE INTERNET OF THINGS

Mario Cardullo and William Parks's *U.S. Patent 3,713,148* in 1973 [1] was recognized as the first ancestor of modern Radio Frequency Identification (RFID). The inventors provided an application scenario, the automated toll collection system, which becomes quite common today. In June 2003, Wal-Mart mandated its top 100 suppliers to attach RFID tags to their pallets and cases shipped to stores in Dallas, Texas region. Wal-Mart also put other smaller suppliers in its supply chain on the agenda of implementing RFID tags. The visibility and convenience brought by RFID saves Wal-Mart significant time and money, and at the same time, lower its supply chain risks.

As RFID is an indispensable component in the blueprint of the internet of Things (IoT) [2], it is far less exciting than the IoT vision. Since Kevin Ashton at MIT introduced the term "internet of things" in 1998, it has been rapidly developed. In 1999, the *Auto-ID Labs*, the research-oriented successor of MIT Auto-ID center, defined IoT as "a network formed by connecting hundreds and thousands of things into Internet through wireless communication." Later in 2005, the International Telecommunication Union (ITU) published an executive summary on IoT. IBM also highlighted "connecting objects to the Internet and applying intelligence and services on top of that" in the big picture of smarter planet in 2008, and further interprets in 2010 that "IoT puts computational power into things no one would recognize as computers. Things like cars, appliances, roadways and rail lines, power grids, clothes."

The emerging technology of IoT enables full visibility of the world, allows intensive communication among objects, and equips objects with appropriate level of intelligence. With the exciting capabilities, we are able to improve, or even radically change the way we live [3], and the way we operate our businesses [4].

In China, the government and enterprises have been greatly promoting the development of IoT:

- The State Council has listed the IoT industry as one of the five strategic emerging industries in China.
- In 2009, Chinese Premier Wen, Jia Bao called for the rapid development of the IoT technology in his speech at the city of Wu'xi.
- In 2009, China Mobile, Chine Unicom, Chine Telecom, Huawei, ZTE, Datang, Lenovo and other companies jointly set up the China Industry Alliance of IoT in Wuxi.

Given the promising benefits of IoT, we focus specifically on how IoT will enable the supply chain innovation. In the following, we will first review the IoT literature in **Section II** to better understand IoT from four dimensions, i.e. the definition, the technology, IoT ecosystem and business values; we will then propose a business model in **Section III** to describe how IoT may help the supply chain innovation in the material flow, information flow and capital flow as well as carbon footprint control. In **Section IV** we come up with several interesting academic problems, and finally we close our paper with challenges and opportunities brought by IoT in **Section V**.

II. LITERATURE REVIEW

In this section, we try to scope IoT from four perspectives. The *definition* summarizes what is the Internet of Things; the *technology* employed by IoT reveals how we can construct it; the *IoT ecosystem* shows the vision on IoT industry chain and the *business values and application scenarios* describe what we can achieve with IoT.

A. The Definition of IoT

Different definitions on IoT emphasize different facets of this technology. According to the white paper jointly published by several European organizations, the Internet of Things is "*Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts*" when considering its functionality and identity; it is also "*Interconnected objects having an active role in what might be called the Future Internet*" if we emphasize the seamless integration; and with a little more technological flavor, it becomes

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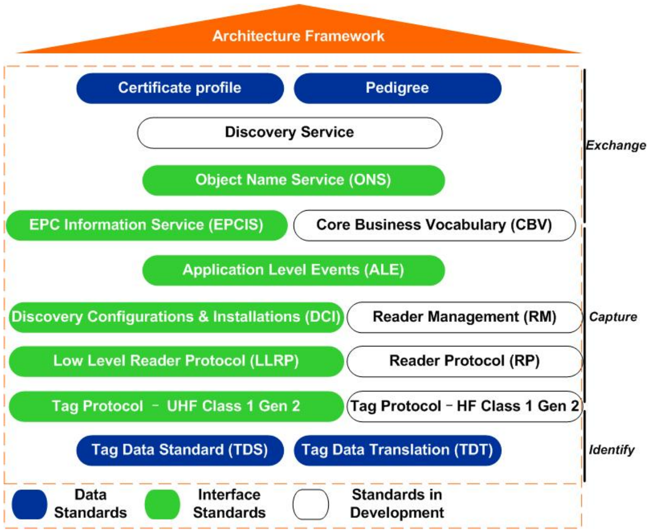


Figure 1. The standards architecture framework from EPCglobal (Source: http://www.epcglobalinc.org/standards/)

"*a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols*." [5]

Haller et al. [6] views IoT as a bridge between the physical world and its representation in the information world and therefore defines it as: "*A world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these smart objects over the Internet, query their state and any information associated with them, taking into account security and privacy issues.*"

We may liken sensors and actuators in IoT to nerve cells and muscles of human body, the interconnection in IoT to nervous system, and models & advanced analytics to brain. We would like to stress the embedded intelligence of IoT in our understanding: "*Global system of interconnected physical objects, people and IT systems supported by innovative and affordable data collection, networking and analytics technologies, to enable intelligent sense, prediction and response to physical world situations.*"

B. The Technology of IoT

To facilitate data identification, capture and exchange among smart objects in IoT, we need well-defined standards.

EPCglobal is one of the best-known organization devoting to achieve worldwide adoption and standardization of *electronic product code* (EPC) technology, and the EPC network is an example IoT scheme. Fig. 1 shows its architecture framework of standards.

Claiming that the EPC architecture tends to be RFID and supply chain management (SCM) centric, Främling and Nyman [7] proposes another architecture to address specifically the increasingly urgent issue of product lifecycle information management.

TABLE I
SUMMARY OF SMART OBJECT TYPES

Object type	Awareness	Function
Activity-aware	Activities	Data log
Policy-aware	Rules	Data accumulation and threshold warnings
Process-aware	Work process	Context-driven work guidance and alerts

For the smart objects, Kortuem et al. [8] categorizes them into activity-aware objects, policy-aware objects and process-aware objects, as summarized in Table I.

C. The IoT Ecosystem

According to [9], IoT can be architecturally divided into the sensing, communication, management and application layers. We believe that the IoT emergence is driving the prosperity of the whole industry value chain. Potential participants of each layer are described below:

- Sensing layer involves suppliers for sensor chips, communication chips, communication modules, hardware system integrators, M2M providers and embedded software providers.
- Communication layer offers markets for Internet access providers, Internet service providers, etc.
- Management layer create opportunities for middleware, industry suites, and industry application solutions providers.
- Application layer may include system integrators, application providers, etc.

D. Business Value and Application Scenarios

IoT may benefit businesses and consumers by seven value drivers, according to Dr. Fleisch [10] from the Auto-ID Labs. We list the seven value drivers and their sample applications below:

- *Simplified manual proximity trigger*: It works if smart objects can communicate their IDs when manually moved into the roaming space of a reader or sensor. Self check out in libraries and access control in buildings are good examples.
- *Automatic proximity trigger*: It triggers a transaction automatically when the physical distance between two objects exceeds a threshold. Automatic inventory management system and asset-tracking system belong to this category.
- *Automatic sensors trigger*: This value driver supports a rich variety of data types to be collected other than IDs, e.g. temperature, humidity, acceleration, chemical composition, etc. Possible applications include management of perishable goods and condition

monitoring.

- *Automatic product security*: It requires equipping smart objects with some security technologies such as cryptography. It may be used in anti-counterfeiting.

- *Simple direct user feedback*: This value driver provides the smart objects with simple mechanism (e.g. a beep) to feedback humans. With the feedback, the production lot may show its next job, and perishable goods may tell its quality status.

- *Extensive user feedback*: This value driver extends the simple feedback to rich services. Under this context, your mobile phone may serve as city and museum guide or perform allergy test.

- *Mind changing feedback*: The intelligence embedded in the smart objects may change our mind at this level of application. For example, one may tend to save energy if a smart meter continuously shows how much water or electricity has been consumed.

In the next section, we will specifically explore how we can innovate in supply chain management under the IoT context.

III. SUPPLY CHAIN INNOVATION UNDER IOT

It is widely accepted that RFID technology serves as a key enabler to IoT, but IoT is far more capable than the current RFID applications. Considering the timeliness, RFID data can only be collected and transmitted when both the Internet and readers are ready, where the IoT data is supposed to be available (nearly) at any time thanks to the full coverage of IoT network. As for the functionality, RFID supports identifying, addressing and information storage. Inheriting this ability, IoT further actively senses a rich variety of other information, such as humidity, geographic location, weather, labor hours, transport history, etc. Moreover, IoT allows executable codes and computing ability installed on smart objects, resulting in more intelligent objects than those with RFID tags. Table II summarizes the differences.

With better visibility provided by RFID, we can analyze the supply chain performance in finer granularity and improve its performance accordingly [11] [12]. With the *real-time full visibility* provided by IoT, supply chains are evolving to become more and more cost-effective, information-shared and environmental-aware.

As we notice, a supply chain can be abstracted to material flow, information flow and capital flow [13] [14]. Meanwhile, we cannot ignore the urgent call to control carbon footprint in the supply chain, as pointed out by Carbon Trust [15], an independent and not for profit organization setup by UK government. Following we will provide application examples to show how IoT may help the three flows and carbon footprint control to create value for the supply chain.

TABLE II
DIFFERENCES BETWEEN RFID AND IOT

	RFID	**IoT**
Timeliness	When Internet and readers are available	Real-time
Functionality	Identifying, addressing and data storage	Identifying, addressing, data storage and active sensing a rich variety of information
Intelligence	Little	Appropriate level of intelligence

In the model, we categorize the value of IoT to the supply chain innovation by three levels: direct technology benefits, business process transformation, and new business model emergence.

A. Direct Technology Benefits

Direct technology benefits refer to the scenarios where we can speedup or enhance the old processes as a result of the technological progress.

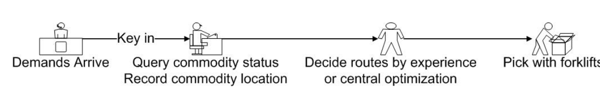
- *Material flow*: IoT makes a faster customs clearance in cargo transportation, since data on multiple objects can be collected at the same time with little manpower, thanks to the wireless technology. Similarly, it can speedup the goods movement into and out of the warehouses, as a result of the expedited check-in/check-out procedures.

- *Information flow*: With IoT, the customer is able to query rich information on his/her parcels, cargos or containers (geographic location, delay or not, the reason for delay, the handlers, etc.) at any time, which contrasts with the current intermittent update on parcel information offered by the logistics service providers.

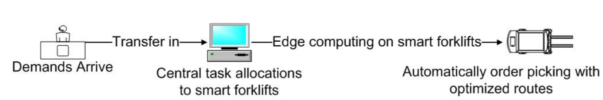
B. Business Process Transformation

Business process transformation refers to the scenarios where we modify existing business process to increase efficiency, reduce cost, save energy and/or improve customer satisfactions, with the intelligence, real-world visibility and real-time communication in IoT.

- *Material flow*: The order picking problem in the warehouse is to pick multiple types of commodities to satisfy independent customer demands. The order picker tries to minimize the traveling distance for time and energy saving via route optimization and order consolidation. One of the most commonly adopted process is:



With networked smart objects, we may transform the process as:



In the transformed process, we do not need central optimization to schedule all the forklifts, but allow the forklifts to query commodity status and optimize their routes within their responsible area independently. Therefore we decompose the serial commodity status query and order picking to distributed subtasks based on area division, which saves time and reduces the computing load of the central computer.

In the express network, the couriers are responsible for certain delivery and uncertain demands of new pick-up orders. As the order delivery routes can be centrally optimized before their departures from the transfer center, the couriers in fact need real-time optimization of their routes to accommodate randomly rising pick-up demands. IoT technology may enable executable optimization algorithms on the terminals of couriers, and therefore help the couriers to choose the best paths within their responsible area. As a result, time, cost and energy can be saved with customer satisfaction improved.

- *Information flow*: One major cause of the well-known bullwhip effect in the supply chain is the information distortion ([16]), i.e. each participant can only capture the demand fluctuation of its direct downstream participant instead of the true customer demand on final product. In the IoT context, the sale of a final product will immediately trigger the information sharing along the whole supply chain, and thus eliminate the information distortion or delay. The demand prediction transforms from the traditional information chain-based to real demand-based.

  Another example stands out if sensors can easily detect the quality status of perishable goods in real-time. Knowing the quantity and containers (IDs, locations, etc.) of perishable goods in advance of arrival, not only do we remove the quality checking procedure, but also we may prepare the disposal equipments, chemical composites, etc., ahead of time. This process transformation saves time and optimizes the resource allocation.

C. New Business Model Emergence

New business model emergence embodies the scenarios where we create and support new businesses that were unavailable or infeasible in the past.

- *Capital flow*: To facilitate the capital flow in the supply chain, there is a converging demand to finance the supply chain by financial institutions. One way is to finance against inventory in transit, which requires high visibility in transportation to mitigate financial institutions' risks. With lower risks, financial institutions may charge lower loan rate, which will in return benefits the whole supply chain. Before the IoT appearance, only logistics service providers may finance the goods transported by their own fleets. With IoT technology, financial institutions can actively participate the process and better the supply chain capital flow with their remarkable capital capability.

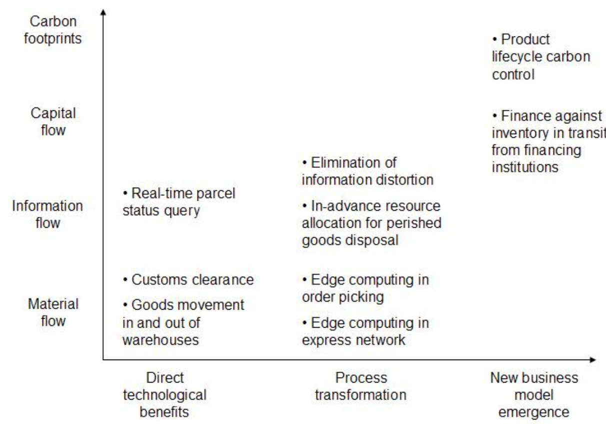


Figure 2. Supply chain innovation model summary

- *Carbon footprint*: Given the complicity of global supply chain, the carbon footprint related issues are not easy to capture. However, IoT can enable the capture process. As we have recognized, the benefits of IoT in carbon control are three-fold. First, we are about to make the *carbon dioxide emissions* of final products highly visible because smart subcomponents mark the carbon footprint of their own, including footprint in production, transportation, etc. Second, IoT can record the *carbon credit trade history* aside from the emissions, which help the environmental department to ensure the regulation compliance. Third, carbon dioxide can be used by food industry(carbonated drink, baking powder), chemistry industry, oil industry, etc. IoT network can automatically *match supply chain carbon source with carbon demand*, therefore we can greatly enhance a green supply chain.

We plot the above sample scenarios of our supply chain innovation vision in the IoT context in Fig. 2, which illustrates how IoT drives the supply chain innovation at different levels. All of these innovation scenarios originate from the characteristics of IoT in Table II. The wireless technology speedups the customs clearance as well as the goods movement in and out of warehouses; the real-time and real-world visibility supports parcel status queries; the embedded intelligence facilitates the process decomposition in order picking and express network; the real-time and real-world information sharing leads to accurate demand prediction and improved resource utilization; the full visibility also helps to release the frozen capital in the chain, and the historic records of carbon footprint help greatly in environment protection.

IV. PROBING FURTHER

In face of the powerful IoT technology, we propose several challenging but interesting issues in supply chain management for domain experts.

1) *Base station layout*: Data are transferred via base stations. We would like to cover the most space with the least number of base stations, considering the reliability issues and features of data flows. Can we utilize and consolidate the existing base stations of telecommunication industry or the public WAN? And to what extent? Can we employ the sound modeling and algorithmic techniques of warehouse layout in the supply chain, of course, with some modifications?

2) *Real-time v.s. near-real-time*: The real-time access to information in IoT definitely enhance our decision-making but with considerable investments in hardware and software to support. However, in the supply chain (and many other applications) we make decisions at discrete time epochs, and only require necessary information by then. If we understand the supply chain dynamics and access data when in need, the network may allocate the surplus capacity to other applications.

3) *Edging data mining*: The capability of collecting large quantity and types of data may become a heavy burden on data exchange. However, with intelligence on smart objects, we may perform some pre-processing on data and only send out those condensed, useful information. During the process, two or multiple smart objects may collaborate to perform data mining, and then send results to the destination, just like (inner or outer) "join" of two/multiple tables in the database operations. How can we leverage our obtained insight of supply chain management to define the relationships and operations of a set of smarter objects are left to be studied.

4) *Information pricing*: Is it possible to charge on information in the IoT era? And how do we evaluate the value of a piece of information? For instance, the direct seller to the final customer enables the sensor to collect useful information, should he/she charge his/her upstream suppliers for it? If yes, at what price? Symmetrically, the upstream suppliers may hold information on the supply fluctuation which is desired by the downstream players. It becomes a game between the supply chain participants. Another possibility is that a third party collects, cleanses and processes data for the supply chain participants. So, at what price? Many researchers have studied the pricing problem in the supply chain, which may be referred to.

V. Challenges and Opportunities

IoT offers us as many challenges as opportunities. Companies that have ambitions in IoT should understand and prepare to overcome the challenges while grasp the opportunities to become more competitive.

A. Challenges

Haller et al. [6] believes four technological issues are challenging during IoT implementation, including the Internet scalability, identification & addressing, heterogeneity of smart objects and service paradigms. [17] provides detailed analysis on the challenges in access control. We have identified three major sources of challenges for IoT management:

- Governance: IoT governance includes the object naming, assigning authority, addressing mechanism, the information repository, and ethical framework, etc. Proper governance avoid the mishandling of data and unsuitable assigning of rights.

- Privacy and security: Technically sound solution are needed to guarantee privacy and the security of the customers in order to have a widespread adoption of any object identification system.

- Standards: We call for standards to ensure the data identification, capture and exchange, including heterogeneous data exchange, network transmission, equipment interoperability, end to end security, IoT middleware, device self-configuration and self-management, etc.

B. Opportunities

As we are acting to close the gaps towards a true global IoT, and we may envision an even better one. We would like to suggest that we can incorporate advanced analytics and optimization techniques into IoT, including mathematical modeling, statistics, and operations research, etc. Currently, IBM is summoning experts in mathematics, telecommunication, electronic engineering, computer science, automation as well as control and security to conduct insightful research in IoT, to tailer solutions for enterprises in IoT context and to create a smarter planet in the future.

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