BUSHOR-1218; No. of Pages 10
ARTICLE IN PRESS

Business Horizons (2015) **xxx**, xxx—xxx

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The Internet of Things (IoT): Applications, investments, and challenges for enterprises

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KEYWORDS
Cloud computing;
Internet of Things;
Radio frequency identification;
Real options;
Supply chain management

Abstract The Internet of Things (IoT), also called the Internet of Everything or the Industrial Internet, is a new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other. The IoT is recognized as one of the most important areas of future technology and is gaining vast attention from a wide range of industries. This article presents five IoT technologies that are essential in the deployment of successful IoT-based products and services and discusses three IoT categories for enterprise applications used to enhance customer value. In addition, it examines the net present value method and the real option approach widely used in the justification of technology projects and illustrates how the real option approach can be applied for IoT investment. Finally, this article discusses five technical and managerial challenges.

1. The Internet of Things (IoT)

The Internet of Things (IoT), also called the Internet of Everything or the Industrial Internet, is a new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other. The IoT is recognized as one of the most important areas of future technology and is gaining vast attention from a wide range of industries. The true value of the IoT for enterprises can be fully realized when connected devices are able to communicate with each other and integrate with vendor-managed inventory systems, customer support systems, business intelligence applications, and business analytics.

Gartner (2014) forecasts that the IoT will reach 26 billion units by 2020, up from 0.9 billion in 2009, and will impact the information available to supply chain partners and how the supply chain operates. From production line and warehousing to retail delivery and store shelving, the IoT is transforming business processes by providing more accurate and real-time visibility into the flow of materials and products. Firms will invest in the IoT to redesign factory workflows, improve tracking of materials, and optimize distribution costs. For example, both John Deere and UPS are already using IoT-enabled fleet tracking technologies to cut costs and improve supply efficiency.

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0007-6813/$ — see front matter © 2015 Kelley School of Business, Indiana University. Published by Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.bushor.2015.03.008

In addition to manufacturers' adoption of the IoT, various service industries are in the process of adopting the IoT to increase revenue through enhanced services and become leaders in their markets. Disney's MagicBand is a new wristband with RFID chips that serves as a ticket and connects to Disney's data repository regarding park visitors. Kroger's new IoT-based system, Retail Site Intelligence, is one complete retail platform of video analytics, wireless devices, POS devices, handheld sensors, IP cameras, and video management software that was designed to help customers have a better shopping experience by more easily finding the products they want and saving time at checkout.

The adoption of this technology is rapidly gaining momentum as technological, societal, and competitive pressures push firms to innovate and transform themselves. As IoT technology advances and increasing numbers of firms adopt the technology, IoT cost-benefit analysis will become a subject of great interest. Because of the potential but uncertain benefits and high investment costs of the IoT, firms need to carefully assess every IoT-induced opportunity and challenge to ensure that their resources are spent judiciously.

This article begins with a discussion of the five essential IoT technologies used for the deployment of successful IoT-based products and services and identifies three IoT categories for enterprise applications. Then, it examines a net present value approach and a real option approach widely used in the justification of technology projects and discusses how real option valuation can be applied to IoT investment. Finally, this article discusses five technical and managerial challenges: data management, data mining, privacy, security, and chaos.

2. Essential IoT technologies

Five IoT technologies are widely used for the deployment of successful IoT-based products and services:

1. radio frequency identification (RFID);
2. wireless sensor networks (WSN);
3. middleware;
4. cloud computing; and
5. IoT application software.

2.1. Radio frequency identification (RFID)

Radio frequency identification (RFID) allows automatic identification and data capture using radio waves, a tag, and a reader. The tag can store more data than traditional barcodes. The tag contains data in the form of the Electronic Product Code (EPC), a global RFID-based item identification system developed by the Auto-ID Center. Three types of tags are used. *Passive* RFID tags rely on radio frequency energy transferred from the reader to the tag to power the tag; they are not battery-powered. Applications of these can be found in supply chains, passports, electronic tolls, and item-level tracking. *Active* RFID tags have their own battery supply and can instigate communication with a reader. Active tags can contain external sensors to monitor temperature, pressure, chemicals, and other conditions. Active RFID tags are used in manufacturing, hospital laboratories, and remote-sensing IT asset management. *Semi-passive* RFID tags use batteries to power the microchip while communicating by drawing power from the reader. Active and semi-passive RFID tags cost more than passive tags.

2.2. Wireless sensor networks (WSN)

Wireless sensor networks (WSN) consist of spatially distributed autonomous sensor-equipped devices to monitor physical or environmental conditions and can cooperate with RFID systems to better track the status of things such as their location, temperature, and movements (Atzori, Iera, & Morabito, 2010). WSN allow different network topologies and multihop communication. Recent technological advances in low-power integrated circuits and wireless communications have made available efficient, low-cost, low-power miniature devices for use in WSN applications (Gubbi, Buyya, Marusic, & Palaniswami, 2013).

WSN have primarily been used in cold chain logistics that employ thermal and refrigerated packaging methods to transport temperature-sensitive products (Hsueh & Chang, 2010; White & Cheong, 2012). WSN are also used for maintenance and tracking systems. For example, General Electric deploys sensors in its jet engines, turbines, and wind farms. By analyzing data in real time, GE saves time and money associated with preventive maintenance. Likewise, American Airlines uses sensors capable of capturing 30 terabytes of data per flight for services such as preventive maintenance.

2.3. Middleware

Middleware is a software layer interposed between software applications to make it easier for software developers to perform communication and input/output. Its feature of hiding the details of different technologies is fundamental to free IoT developers from software services that are not directly relevant to the specific IoT application. Middleware gained popularity in the 1980s due to its major role in simplifying the integration of legacy technologies into new ones. It also facilitated the development of new services in the distributed computing environment. A complex distributed infrastructure of the IoT with numerous heterogeneous devices requires simplifying the development of new applications and services, so the use of middleware is an ideal fit with IoT application development. For example, Global Sensor Networks (GSN) is an open source sensor middleware platform enabling the development and deployment of sensor services with almost zero programming effort. Most middleware architectures for the IoT follow a service-oriented approach in order to support an unknown and dynamic network topology.

2.4. Cloud computing

Cloud computing is a model for on-demand access to a shared pool of configurable resources (e.g., computers, networks, servers, storage, applications, services, software) that can be provisioned as Infrastructure as a Service (IaaS) or Software as a Service (SaaS). One of the most important outcomes of the IoT is an enormous amount of data generated from devices connected to the Internet (Gubbi et al., 2013). Many IoT applications require massive data storage, huge processing speed to enable real-time decision making, and high-speed broadband networks to stream data, audio, or video. Cloud computing provides an ideal back-end solution for handling huge data streams and processing them for the unprecedented number of IoT devices and humans in real time.

2.5. IoT applications

The IoT facilitates the development of myriad industry-oriented and user-specific IoT applications. Whereas devices and networks provide physical connectivity, IoT applications enable device-to-device and human-to-device interactions in a reliable and robust manner. IoT applications on devices need to ensure that data/messages have been received and acted upon properly in a timely manner. For example, transportation and logistics applications monitor the status of transported goods such as fruits, fresh-cut produce, meat, and dairy products. During transportation, the conservation status (e.g., temperature, humidity, shock) is monitored constantly and appropriate actions are taken automatically to avoid spoilage when the connection is out of range. For example, FedEx uses SenseAware to keep tabs on the temperature, location, and other vital signs of a package, including when it is opened and whether it was tampered with along the way.

While device-to-device applications do not necessarily require data visualization, more and more human-centered IoT applications provide visualization to present information to end users in an intuitive and easy-to-understand way and to allow interaction with the environment. It is important for IoT applications to be built with intelligence so devices can monitor the environment, identify problems, communicate with each other, and potentially resolve problems without the need for human intervention.

3. IoT applications to enhance customer value

Despite growing popularity of the IoT, few studies have focused on categorization of the IoT for enterprises (e.g., Chui, Löffler, & Roberts, 2010). Based on the technology trends and literature review, this article identifies three IoT categories for enterprise applications: (1) monitoring and control, (2) big data and business analytics, and (3) information sharing and collaboration. Understanding how these three IoT categories can enhance the customer value of an organization is a prerequisite to successful IoT adoption. This article next discusses the three IoT categories, along with an illustration of real-world IoT applications developed to enhance customer value.

3.1. Monitoring and control

Monitoring and control systems collect data on equipment performance, energy usage, and environmental conditions, and allow managers and automated controllers to constantly track performance in real time anywhere, anytime. Advanced monitoring and control technologies such as smart grid and smart metering reveal operational patterns, spot areas of potential improvement, or predict future outcomes and optimize operations, leading to lower costs and higher productivity.

The smart home is known to be at the forefront of innovation regarding IoT monitoring and control systems. The primary value propositions are family and property protection and energy savings. For example, the Verizon Home Monitoring and Control network uses a wireless communications technology designed specifically for remote control applications in home automation. IoT-enabled home appliances and devices can be monitored and controlled outside the user's home through a computer, tablet, or smartphone. The Verizon Home Monitoring and

Control network allows users to adjust the lights, control the climate, manage the security system, receive automatic event notifications, and even lock and unlock doors.

The IoT is also used to monitor and control various components in cars. The primary customer value propositions are drivers' personalized experience and satisfaction. Ford and Intel teamed up in 2014 to explore new opportunities to personalize the user experience using facial recognition software and a mobile phone app. The joint research project, called Mobile Interior Imaging, incorporates perceptual computing technology to offer improved privacy controls and to identify different drivers and automatically adjust features based on an individual's preferences. The in-car experience is then personalized further by displaying information specific to the driver, such as his/her calendar, music, and contacts. The customer value propositions are appropriately integrated into the connected car environment to provide another revenue stream for Ford.

3.2. Big data and business analytics

IoT devices and machines with embedded sensors and actuators generate enormous amounts of data and transmit it to business intelligence and analytics tools for humans to make decisions. These data are used to discover and resolve business issues—such as changes in customer behaviors and market conditions—to increase customer satisfaction, and to provide value-added services to customers. Business analytics tools may be embedded into IoT devices, such as wearable health monitoring sensors, so that real-time decision making can take place at the source of data.

The IoT and advances in business analytics now make it possible to capture vast amounts of individual health data. The IoT enables healthcare service providers to personalize patient care. New IoT technologies provide data about a patient's everyday behaviors and health, creating opportunities for care providers to influence patients far more frequently and effectively. For example, Humana's Healthsense eNeighbor® remote monitoring system reports changes in the member's normal patterns of movement and activity to Humana care managers—via in-home sensors that measure routine daily activities with data analytics—to help trigger interventions and help prevent adverse events from escalating to emergency room visits or hospital stays.

IoT-based big data are also transforming the healthcare product industry. For example, Proctor & Gamble developed the Oral-B Pro 5000 interactive electric toothbrush to provide users with a smarter, more personalized oral care routine. The interactive electric toothbrush records brushing habits with mobile technology while giving mouth-care tips alongside news headlines. This innovation provides users with unprecedented control over their oral care. Tests of the interactive electric toothbrush have shown that when connected, brushing time increases from less than 60 seconds with a manual toothbrush to 2 minutes and 16 seconds with an electric toothbrush, surpassing the 2-minute session recommended by dental professionals.

3.3. Information sharing and collaboration

Information sharing and collaboration in the IoT can occur between people, between people and things, and between things. Sensing a predefined event is usually the first step for information sharing and collaboration. In the supply chain area, information sharing and collaboration enhance situational awareness and avoid information delay and distortion. For example, if sensors are placed throughout a retail store where refrigeration is necessary, alerts can be sent to the store manager's mobile device whenever the refrigerators malfunction. The manager can then check the employee status report to see who is available and send task assignments to that employee via his or her IoT-enabled mobile device.

To enhance information sharing and collaboration with shoppers, Macy's is deploying shopkick's shopBeacon technology, an enhanced mobile location-based technology that uses ultrasound Bluetooth Low Energy (BLE). ShopBeacon provides shopkick app users with personalized department-level deals, discounts, recommendations, and rewards. As shoppers enter Macy's, shopBeacon reminds those shopkick app users who have opted in. This enhancement in Macy's information sharing with shoppers allows for increased consumer engagement and promotional and marketing relevancy that lead to higher customer satisfaction and increase revenues. In September 2014, following a pilot test of the application, Macy's decided to roll out shopBeacon in all of its 4,000 U.S. locations. Other major retailers such as Target, American Eagle Outfitters, and JCPenney also partnered with shopkick and launched shopBeacon in 2014. Due to competitive pressure, there is expected to be a rapid adoption of shopBeacon at other national retailers, too.

4. Evolution of the foundational IoT technologies

Various types of IoT applications have emerged, and the willingness of enterprises to utilize them is growing rapidly. According to Bradley, Barbier, and Handler (2013), the IoTwill generate $14.4 trillion in value; the combination of increased revenues and lower costs will migrate among companies and industries from 2013 to 2022. From an industry perspective, four industries make up more than half of the $14.4 trillion in value. These leading four industries in terms of value at stake include manufacturing at 27%; retail trade at 11%; information services at 9%; and finance and insurance, also at 9%. Other industries such as wholesale, healthcare, and education lag behind in terms of value generation, with a range between 1% and 7%. Much of the value for manufacturers comes from greater agility and flexibility in factories, and from the ability to make the most of workers' skills. Additionally, a large amount of the value for retailers comes from connected marketing and advertising. Geographic distributions of the value are heavily driven by each region's relative economic growth rate and by the relative size of industry sector in each region. In the United States, $4.6 trillion of value is most prevalent in the services area. However, in China, $1.8 trillion of value is derived from rapid economic growth, mainly in the manufacturing sector.

Table 1 shows projected evolution in the area of foundational IoT technologies: network, software and algorithms, hardware, and data processing. The network is the backbone of the IoT. It refers to uniquely identifiable objects (things) and their virtual representations in an Internet-like structure. Network technology is moving to unobtrusive wire-free communication technology that allows device-to-device applications to be deployed more flexibly. Network technology is evolving toward a context-aware autonomous network.

Objects rely on software to communicate effectively with each other and to deliver enhanced functionality and connectivity. Software should be developed with the IoT's interoperability,

Table 1. Evolution of key IoT technologies

	Before 2010	2010—2015	2015—2020	Beyond 2020
Network	• Sensor networks	• Self-aware and self-organizing networks • Sensor network location transparency • Delay-tolerant networks • Storage networks and power networks • Hybrid networking technologies	• Network context awareness	• Network cognition • Self-learning, self-repairing networks
Software and Algorithms	• Relational database integration • IoT-oriented RDBMS • Event-based platforms • Sensor middleware • Sensor networks middleware • Proximity/ Localization algorithms	• Large-scale, open semantic software modules • Composable algorithms • Next generation IoT-based social software • Next generation IoT-based enterprise applications	• Goal-oriented software • Distributed intelligence, problem solving • Things-to-Things collaboration environments	• User-oriented software • The invisible IoT • Easy-to-deploy IoT software • Things-to-Humans collaboration • IoT 4 All
Hardware	• RFID tags and some sensors • Sensors built into mobile devices • NFC in mobile phones • Smaller and cheaper MEMs technology	• Multiprotocol, multistandards readers • More sensors and actuators • Secure, low-cost tags (e.g., Silent Tags)	• Smart sensors (biochemical) • More sensors and actuators (tiny sensors)	• Nanotechnology and new materials
Data Processing	• Serial data processing • Parallel data processing • Quality of services	• Energy, frequency spectrum-aware data processing • Data processing context adaptable	• Context-aware data processing and data responses	• Cognitive processing and optimization

Source: Adapted from Sundmaeker, Guillemin, Friess, and Woelfflé (2010, p. 74) connectivity, privacy, and security requirements in mind. The focus of software development is shifting to user-oriented, distributed intelligence and machine-to-machine and machine-to-human collaboration.

The news that Google is paying $3.2 billion in cash to buy Nest, a smart thermostat business, demonstrates the value of hardware in the IoT. Hardware is innovatively designed and robustly produced, driven by the consumerized IoT devices which have myriad features, functionalities, and operating environments. While RFID tags and sensors have been the focus of hardware innovation, miniaturization of hardware and nanotechnology is leading the energy-efficient, low-power hardware evolution.

IoT devices generate enormous quantities of data that need to be aggregated and analyzed in real time to provide information regarding status, location, functionality, and environment of the devices. The traditional data processing method does not work well in the real-time streaming data process of the IoT environment. Since processing large quantities of IoT data in real time will increase workloads of data centers at an exponential rate, data processing will become more context-aware, optimized, and cognitive.

In the IoT environment, a large number of devices are connected with each other, and it is not feasible to process all the streaming data available to those devices. Context-aware data processing enables sensors and devices to use context-specific information such as location, temperature, and the availability of a certain device to decide what data to collect and interpret to provide relevant information to other devices or users. For example, context-aware data processing can deliver relevant information to a user by knowing the user's current location (e.g., within a department store, a park, or a museum). Cognitive data processing integrates the human cognition process into IoT applications. Rather than being programmed to deal with every possible data-processing need, a cognitive data-processing application is trained using artificial intelligence algorithms to sense, predict, infer, and learn tasks and environments. For example, cognitive data processing uses image recognition techniques to understand the surrounding environment, processes data for a user, and utilizes feedback from the user to learn further. The optimization of data processing is critical to timely processing of the continuous stream of massive amounts of data. Technological advances in optimized data processing help make timely decisions in time-critical big data applications such as smart grids, environmental monitoring, and smart manufacturing.

5. IoT investment opportunities and evaluation (net present value vs. real option approach)

Our survey shows the IoT is penetrating a wide range of industries including retailing, manufacturing, healthcare, insurance, home appliances, heavy equipment, airlines, and logistics. The benefits of IoT technologies such as RFID-based merchandise tracking and home networking are concrete and immediately measurable. Other IoT technologies such as intelligent automobiles and intelligent hospital robot systems are in the experimental stage and their benefits may be realized in the long term. While the IoT is relatively new, investment opportunities abound, along with the development of various foundational technologies summarized in Table 1. Companies are expected to take advantage of the wave of IoT innovations in the coming years.

In general, companies are going to take an immediate investment or a wait-and-see approach to investment based on the maturity level of the specific IoT technologies. This section discusses two investment evaluation methods widely used in the justification of technology projects.

5.1. Net present value and real option approach

With so much potential value in the investment of IoT technology, firms need an appropriate measure by which to properly assess its risks and rewards. The standard measure firms typically use to value projects, net present value (NPV), is inappropriate to use for several reasons. Chief among these in this circumstance is that it ignores flexibility in investment such as reversibility and scalability in the evaluation horizon. No other technology investment has the flexibility that information technology investments in general have (Fichman, Keil, & Tiwana, 2005). All of the aforementioned IoT technologies may have had value arising from flexibility in investment. Thus, NPV tends to undervalue a project's worth and is not suitable for high-risk projects. In order to value the IoT more appropriately, real option valuation may be an appropriate evaluation method. The following section discusses how the real option valuation can be applied for IoT investment.

5.2. Real options

As implied by their namesake, real options are the right—but not the obligation—to take an action during a period of time. These include the options to expand, contract, and wait. Real options can

Table 2. Types of real option approaches

Type of Option	Description
Option to Abandon/Switch	This option gives management the option to abandon a project that is operating at a loss and sell or redeploy the assets.
Option to Contract	Similar to the option to abandon, this gives management the option to scale back a project that is operating at a loss.
Option to Defer/Postpone	This gives management the option to wait/learn more to see if a project will be profitable.
Option to Expand	This gives management the option to expand/scale up the project based on its success.

prove particularly valuable in fields of high uncertainty and risk, such as information technology. As reviewed by Li and Johnson (2002), two main characteristics make real options an appropriate application for IT investments. First, IT projects typically require high initial investments and are often irreversible. Second, IT investments can have very high uncertainty and risk. IT projects such as IoT projects inherently contain technical uncertainty as well as market uncertainty (Fichman et al., 2005). Also, IT can advance at a rapid pace and change direction quickly. These characteristics make real option valuation ideal in valuing IoT investment projects, as it can capture value that otherwise would be overlooked.

Good managers intuitively understand real options. They understand that simple cash profits are not the only value a project can add; other opportunities may arise from engaging in projects. Real option valuation allows management to quantify these options to more accurately reflect the value of a project and to have a real strategic impact on the value of a project. Table 2 lists four general types of real options.

There are several examples of how real options are used in valuation today. Any firm that operates in a field of high uncertainty (e.g., pharmaceuticals) is likely to employ real options. Pharmaceutical companies face uncertainty not only in drug development (akin to IT technical uncertainty) but also in other external factors such as regulations and patents (akin to IT market uncertainty). Real option valuation is also used with movie deals. Movie studios often purchase rights—that is, real options—to produce films. Film rights give the purchasing studio the right but not the obligation to produce a movie. [Note that this is not the cost of producing the movie, simply the value of the right to produce it.] After rights are purchased, studios can then employ surveys and analysis to determine whether or not a production will be profitable. If the timing is not right, these options allow the studio to wait and perhaps produce the film at a later time.

5.3. Valuation

Like financial options, real options can be calculated using the Black-Scholes model or decision trees. For real options, using decision trees may be more appropriate, as that will allow setting up possibilities of the project according to what management believes them to be. When valuing real options, it is especially important to stage the problem correctly and to understand how real options are analogous to financial options. Table 3 provides a guide on how they are related.

S represents the present value of cash flows from the project; X represents the cost to invest in the project; σ^2 represents the riskiness of the project; T represents the period of time in which management can take an action; and r represents the risk-free rate the investment capital would earn.

Using decision trees to calculate the real option value, one can stage the possible values a project can take, exercise the option at the optimal time/value of the project, and discount backward in order to find the value of the option. For example, with a one-period decision tree, we begin with the starting value today, S_0, and move forward one period. The value can either increase to S_u or decrease to S_d. From here we can use the risk-free rate, r, and determine

Table 3. Real options variables

Real Options	Variable	Financial Options
Present Value of Project	S	Current Stock Price
Investment Cost of a Project	X	Option Exercise Price
Riskiness/Uncertainty of the Project	σ^2	Stock Price Uncertainty
Time Window of the Project	T	Time to Expiration
Time Value of Money	r	Risk-free Rate

Source: Adapted from Li & Johnson (2002) the probability of success (p) and failure (1-p), determine the expected payoffs using the project value less the investment amount, and essentially work backward to determine the value of the option.

5.4. Real options example

Here we offer an example. A company is looking to invest in new smart vending machines that will reduce costs and increase profits. Management believes there is a probability of 0.55 that there will be a high demand in this technology with a market value of $140m, and a probability of 0.45 that there will be a low demand in this technology with a market value of $40m. Figure 1 shows a decision tree without real options.

If the cost of investing in this technology at time zero is $100m and the discount rate is 8%, then from a simple NPV calculation the value of the project is −$12.04m, which the standard NPV rejects.

Present Value of Cash In flow

$$= \frac{(140m)(0.55) + (40m)(0.45)}{(1.08)^1} = \$87.96m$$

$$NPV = \$87.96m - \$100m = -\$12.04m$$

However, management can use a real option approach to evaluate this investment as a phased financing and scaling option. The company could start with a pilot project and better learn the market over time. In the following year, management could avoid full investment of $100m into this smart vending machine technology if the market turns out to be $40m, and only invest in this technology if the market turns out to be $140m. Therefore, management can value the option using a decision tree that takes the higher value as the exercised option. The option value of this project from the real option perspective is $(\$140m - \$100m)*0.55 + (\$0m)*0.45 = \$22m/(1.08)^1 = \$20.37m$. As long as the pilot project costs less than $20.37m, this pilot project with a following investment in the smart vending machine technology is worth doing. Figure 2 shows the option value calculation, discounted back one period.

While this example was simplified for readers from non-finance backgrounds, more complicated scenarios can be analyzed using the same principles. Many IoT projects have unclear project scopes and goals and are using breakthrough technologies; in such scenarios, there is a higher risk of project failure and greater irreversibility of investments than with traditional technology projects. Our example highlights the value of real option approaches to IoT projects.

6. Challenges in IoT development

Based on the survey of IoT practices, this section discusses challenges in IoT development by enterprises. As with any disruptive innovation, the IoT will present multiple challenges to adopting enterprises. For example, due to the explosion of data generated by IoT machines, Gartner (2014) suggested that data centers will face challenges in security, the enterprise, consumer privacy, data itself, storage management, server technologies, and data center networking. This section discusses five technical and managerial challenges: data management, data mining, privacy, security, and chaos.

6.1. Data management challenge

IoT sensors and devices are generating massive amounts of data that need to be processed and stored. The current architecture of the data center is not prepared to deal with the heterogeneous nature and sheer volume of personal and enterprise data (Gartner, 2014). Few enterprises would be able to invest in data storage sufficient to house all the IoT data collected from their networks. Consequently, they will prioritize data for operations or backup based on needs and value. Data centers will become more distributed to improve processing efficiency and response time as IoT devices become more widely used and consume more bandwidth.

Figure 1. A decision tree without real options

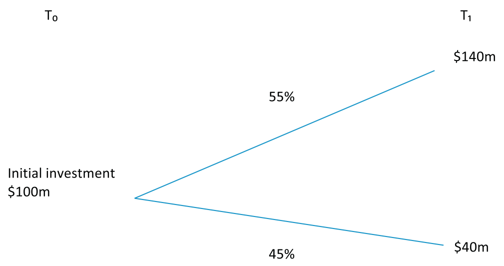
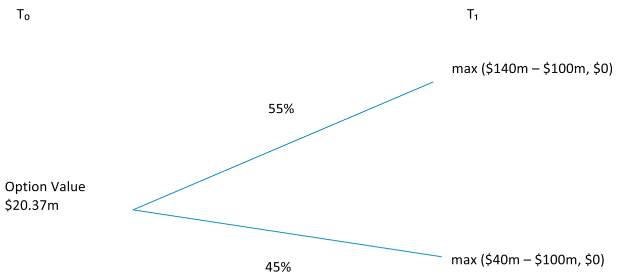


Figure 2. A decision tree with real options



6.2. Data mining challenge

As more data are available for processing and analysis, the use of data mining tools becomes a necessity. Data consist not only of traditional discrete data, but also of streaming data generated from digital sensors in industrial equipment, automobiles, electrical meters, and shipping crates. These streaming data are about location, movement, vibration, temperature, humidity, and even chemical changes in the air. Data mining tools can invoke corrective processes to address immediate operational issues or inform managers of discoveries regarding competitors' strategic moves and customers' preference changes that will impact their short-term and long-term business activities.

Data need to be tamed and understood using computer and mathematical models. Traditional data mining techniques are not directly applicable to unstructured images and video data. Coupled with the need for the advanced data mining tools to mine streaming data from sensor networks and image and video data, there is a shortage of competent data analysts. McKinsey Global Institute estimated that the United States needs 140,000 to 190,000 more workers with analytical skills and 1.5 million managers and analysts with analytical skills to make business decisions based on the analysis of big data (Manyika et al., 2011).

6.3. Privacy challenge

As is the case with smart health equipment and smart car emergency services, IoT devices can provide a vast amount of data on IoT users' location and movements, health conditions, and purchasing preferences—all of which can spark significant privacy concerns. Protecting privacy is often counterproductive to service providers in this scenario, as data generated by the IoT is key to improving the quality of people's lives and decreasing service providers' costs by streamlining operations. The IoT is likely to improve the quality of people's lives. According to the 2014 TRUSTe Internet of Things Privacy Index, only 22% of Internet users agreed that the benefits of smart devices outweighed any privacy concerns (TRUSTe, 2014). While the IoT continues to gain momentum through smart home systems and wearable devices, confidence in and acceptance of the IoT will depend on the protection of users' privacy.

6.4. Security challenge

As a growing number and variety of connected devices are introduced into IoT networks, the potential security threat escalates. Although the IoT improves the productivity of companies and enhances the quality of people's lives, the IoT will also increase the potential attack surfaces for hackers and other cyber criminals. A recent study by Hewlett Packard (2014) revealed that 70% of the most commonly used IoT devices contain serious vulnerabilities. IoT devices have vulnerabilities due to lack of transport encryption, insecure Web interfaces, inadequate software protection, and insufficient authorization. On average, each device contained 25 holes, or risks of compromising the home network. Devices on the IoT typically do not use data encryption techniques.

Some IoT applications support sensitive infrastructures and strategic services such as the smart grid and facility protection. Other IoT applications will increasingly generate enormous amounts of personal data about household, health, and financial status that enterprises will be able to leverage for their businesses. Lack of security and privacy will create resistance to adoption of the IoT by firms and individuals. Security challenges may be resolved by training developers to incorporate security solutions (e.g., intrusion prevention systems, firewalls) into products and encouraging users to utilize IoT security features that are built into their devices.

6.5. Chaos challenge

The evolution of IoT technologies (e.g., chips, sensors, wireless technologies) is in a hyper-accelerated innovation cycle that is much faster than the typical consumer product innovation cycle. There are still competing standards, insufficient security, privacy issues, complex communications, and proliferating numbers of poorly tested devices. If not designed carefully, multi-purpose devices and collaborative applications can turn our lives into chaos. In an unconnected world, a small error or mistake does not bring down a system; however, in a hyper-connected world, an error in one part of a system can cause disorder throughout. Smart home applications and medical monitoring and control systems consist of interconnected sensors and communication devices and controllers. If a sensor of a medical monitoring and control system malfunctions, the controller may receive an incorrect signal, which may prove fatal to the patient. It is not difficult to imagine smart home kits such as thermostats and residential power meters breaking down or being attacked by hackers, creating unexpected safety problems. The Internet bandwidth can get saturated with data traffic of proliferating devices, creating system-wide performance problems. A single device may have an insignificant problem, but for the system as a whole, the chain reactions of other connected devices can become disastrous. To prevent chaos in the hyper-connected IoT world, businesses need to make every effort to reduce the complexity of connected systems, enhance the security and standardization of applications, and guarantee the safety and privacy of users anytime, anywhere, on any device.

7. Conclusion

Because the IoT is such a recent development, there is still a paucity of studies on the social, behavioral, economic, and managerial aspects of the IoT. This makes it very challenging for companies to make informed decisions as regards IoT adoption/implementation. Our article is one of the first studies on a conceptual model of IoT applications for enterprises. In this article we identified three categories of IoT applications: monitoring and control, big data and business analytics, and information sharing and collaboration. We also presented investment opportunities and investment evaluation with NPV and real options. Finally, we discussed five challenges in implementing IoT applications for enterprises.

Acknowledgment

We offer special thanks to Editor Dr. Marc J. Dollinger for his valuable comments and suggestions.

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