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Internet of Things (IoT) in Retail: Bridging Supply and Demand

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Internet of Things (IoT) in Retail: Bridging Supply and Demand

Abstract

A sales channel serves two primary functions: delivering information and products to customers. Omnichannel retailing allows for the decoupling of these two functions because consumers can learn about products through channels that differ from those used to purchase them. This decoupling requires a far more sophisticated inventory and supply chain operation, as well as integration of all customer touchpoints, to match fast-moving supply and demand. We argue that the Internet of Things (IoT) can play a fundamental role in channel integration because it allows companies to rebalance supply and demand. Our claim is supported by several nascent deployments. In classifying IoT initiatives on an opportunity map, we present a strategic framework in which “enabling” refers to the basic capabilities immediately realized by deploying IoT sensor data and “enhancing” refers to the unanticipated benefits following IoT adoption. This framework distinguishes initiatives by the value they create and by their major area of impact (viz., supply or demand). We justify the adoption of IoT in terms of its enabling capabilities, such as increased inventory accuracy, but its true potential resides in the enhancing capabilities at the intersection of supply and demand.

Keywords: internet of things, omnichannel, retailing, RFID, technology adoption

RETAILING FACES A NEW LANDSCAPE

The Internet of Things (IoT) refers to a broad class of connected devices: networks of sensors and wireless devices that can be remotely accessed through the Internet or private networks (Pelino and Gillett, 2016). These devices include temperature and environmental sensors; optical sensors for remote monitoring; and emerging wearable, edible, and implantable sensors for biological use. Sensor networks found early applications in factory automation and the aerospace industry. IoT is now being adopted across multiple vertical market segments for consumer applications and supply chain management (SCM); see Vermesan et al. (2011) for examples. IoT has already transformed traditional business models in areas such as manufacturing, health care, building automation, transportation, and environmental monitoring (Tyo, 2006). One industry with vast potential for IoT is retailing, on which we focus in this article.[1]

The retail industry is highly competitive, so efficiency and growth require not only solid business operations but also innovation. According to the US Commerce Department, the United States saw nearly $5 trillion in 2016 retail sales; over the last decade, US retailing has consistently exhibited a compound annual growth rate ranging from 2% to 3%.[2] Moreover, online competitors are changing the cost structure and profitability of the business model for in-store operations. In light of these circumstances, retailers are turning to information technology and new business models to devise omnichannel strategies to cater to their customers for online, in-store and mobile shopping (Parris et al., 2015).

The rise of omnichannel retailing has introduced a subtle but crucial change in the industry: the decoupling of information provision from product fulfillment (see Bell et al., 2014; Verhoef et al., 2015). This decoupling has occurred because, in effect, omnichannel retailing blurs boundaries between the channels – in stark contrast to the more conventional *multichannel* approach followed by most retailers over the last decade. That is, sales channels were

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[1] For other applications and implications of IoT, we refer the interested reader to Krotov (2017).

[2] See https://www.digitalcommerce360.com/2017/02/17/us-e-commerce-sales-grow-156-2016/

previously self-contained in the sense that product information and product fulfillment were delivered through the same channel. So, for example, a shopper might try on a dress in the store and then purchase it there; similarly, the shopper could check out a shirt on the retailer's website and then order it from that site. This simple, within-channel structure is breaking down in the omnichannel world. Thus different combinations of information provision and product delivery have emerged, such as *showrooming* (browsing at the store but ordering online) and *webrooming* (searching online yet purchasing at the store).

Academics and practitioners alike have noticed that retailers can choose from a wider range of strategies and business models now than before. Yet new opportunities bring new challenges. In particular, the quintessential SCM goal of matching supply and demand (Fisher, 1997) becomes even harder to achieve when information and product delivery are decoupled. Purchases – and the inventory needed to fulfill those purchases – no longer need to coexist in the same channel.

So far, the omnichannel strategy for most retailers has hinged on developing a presence on social networks (Facebook, Instagram, etc.) and then devising ways for customers to shop on their smartphones. However, retailers are now beginning to deploy IoT devices and a new generation of software tools (World Economic Forum, 2017). Initial successes along these lines have been realized – and publicized by companies that include Bloomingdale's, TSI Holdings, and Brookstone – via the use of IoT devices to improve customers' shopping experience by providing recommendations and product information based on their respective buying habits, thus driving in-store sales (Roberti, 2016a).

We shall argue that IoT can play a fundamental role in bridging supply and demand and can act as a countermeasure to the widening gap between information and fulfillment. Previous authors have concluded that retail success in an omnichannel world requires innovations that give the consumer information on products that best match her needs and tastes – but without trying to sell a product that the retailer does not have in stock. This observation serves as our starting point in the next section. Thereafter, we provide a short overview of IoT before introducing a strategic framework that classifies IoT initiatives on an opportunity map. Our framework distinguishes initiatives by the value they create (enabling or enhancing) and their major area of impact (supply or demand). We show how the costs of IoT adoption can be justified: in most cases, those costs are recovered in less than a year through IoT's *enabling* capabilities (i.e., better management of supply and/or demand). Yet we maintain that its true potential resides in its *enhancing* capabilities at the intersection of supply and demand, which we call the IoT "sweet spot". The article concludes by discussing some challenges to IoT implementation.

DECOUPLING INFORMATION AND FULFILLMENT

Omnichannel retailing extends beyond multichannel retailing. Omnichannel retailing involves several new channels (e.g., mobile, showrooms) in addition to such traditional channels as catalogs and brick-and-mortar outlets. However, the most important difference between multichannel and omnichannel retailing is that, in the latter, the channel boundaries are blurred. According to Verhoef et al. (2015), "channels are interchangeably and seamlessly used during the search and purchase process and it is difficult or virtually impossible for firms to control this usage". Thus the formerly unified functions of providing product information and fulfilling product demand are now decoupled.

This decoupling of information and fulfillment results in more opportunities to interact with the customer, but it also substantially complicates the matching of supply with demand. Consider one of the most prominent creations of the omnichannel era: buy online, pick up in store (BOPS). This innovation helps pull shoppers into the store: more than 30% of consumers use BOPS, and at least a fourth of them subsequently make an unplanned purchase (Hardgrave, 2016). Moreover, BOPS eliminates shipping expenses. Despite all these advantages, fewer than half of all US retailers offer BOPS (Kressmann, 2017); of the retailers that do, most "hide" some inventory from online customers. The reason is that BOPS requires high inventory visibility at the store level so that store associates can efficiently find and pick up the items ordered online.

However, inventory inaccuracy is a persistent industry problem (Mou et al., 2017) that omnichannel retailing only aggravates.

Although BOPS is a good example of how omnichannel retailing can unbalance supply and demand, there are many more. For instance, many retailers have adopted some form of ship-from-store; this practice allows stores to serve as fulfillment centers so that local inventory can be used to satisfy omnichannel demand from anywhere. Here, too, there are issues with inaccurate inventory: the pick success rate ranges from 35% to a high of only 60% (Hardgrave, 2016).[3] A 35% rate means that the retailer might have to search for the item in more than one store, which naturally adds to labor costs. The challenges in this environment pertain not only to products *leaving* the store. That is, consumers in an omnichannel world expect that they will be able to *return* products through any channel (Columbus, 2017), which further strains the relationship between supply and demand.

The supply–demand mismatch issues created by some omnichannel initiatives (e.g., BOPS, ship-from-store, unencumbered can be addressed by using passive radio-frequency identification (RFID) tags, a subclass of IoT devices (Finkenzeller, 2015).[4] These tags are wireless sensors that draw their energy from the tag reader's radio waves and so do not require a local power source (e.g., a battery). With advances in RFID technology, the electronic information contained in these devices can be reliably accessed from within several hundred meters – identifying the item and locating its position via a centrally located radio or a collection of RFID readers. Retailers that have adopted RFID include Macy's, the largest US department store chain, which has been RFID-tagging apparel for four years and plans to tag all store inventory within the next few years (Roberti, 2016b). Marks & Spencer was another early adopter, RFID-tagging all its apparel goods at the source in the factory (Swedberg, 2015).

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[3] The *pick success rate* is the percentage of shipment requests that a store is able to fulfill. Unfulfilled requests are usually due to items that are either out of stock or cannot be found.

[4] We use RFID as an example throughout because it is one of the most common forms of IoT used in retailing. For IoT opportunities in other industries, see Krotov (2017).

RFID is an IoT application used extensively to address challenges that result from the decoupling of information and fulfillment. In fact, there is a wide range of IoT devices that can be used for this purpose. These devices, sorted into IoT “thing types”, are reviewed next.

SUMMARY OF IoT THING TYPES

In Table 1 we identify two distinct classes of IoT types presently being used by retailers to manage demand and supply. In this table, “density” refers to the number of devices on the store’s shop floor and in its back room; “throughput” is measured in number of bits of information per second, or the data rate generated by an IoT device. We classify IoT devices into distinct groups by throughput. A higher throughput requires more bandwidth – as well as more storage and processing power.

[[Insert Table 1 about here]]

Demand Side

There are three main demand-side IoT options. First, camera networks are high-throughput IoT devices designed for in-store use. Retailers have adopted these networks for analyzing customer and employee behavior; they are also used for inventory management (when individual items are visible). Camera networks gather data on conversion rate, visit duration, frequency of visit (possibly with facial recognition software), entrance- and exit-path patterns, and interactions between sales associates and customers. Daily analysis is performed to characterize the activity and flow of customers. Software analytics, which are typically cloud hosted, use the transmitted and stored data to optimize the store layout, and to enable efficient mobile marketing via engagement with shoppers through personalized offerings presented on display devices or through “chatbots”. So-called edge appliances (local servers) are deployed in the store to collect and store data and to undertake data mining – that incorporates (say) local weather and recent social network trends – and thereby track customer sentiment. Also, demographic data about a store’s shopping cohort are captured by facial recognition and/or data aggregation from social network feeds; this information can help align inventory with local shoppers.

The second demand-side IoT option relies on smartphones carried by customers and employees to connect via a wireless network as a mobile payment method and (optionally) to track shopper paths during store operation.[5] Although cheaper than a camera network, this option provides much less information about in-store customer behavior and the overall shopping experience. Cisco's connected mobile experience (CMX) system provides location data, dwell times, and analytics to learn how shoppers behave in the store. Shoppers are offered Wi-Fi access and then the system uses a network of wireless access points to follow those who accept. Even if a shopper declines to log on to the Wi-Fi network, he can still be tracked as long as his smartphone's Wi-Fi is turned on (because such a phone periodically broadcasts its unique "media access control" address). The Cisco product provides a cloud-hosted portal for path visualization in addition to various behavioral analytics for specific locations. Apple has developed its own iBeacon technology for the same purpose. Other location-sensing systems based on smartphones employ audio signals or optical cues – such as Starbucks Siren Order, launched in Korea.[6]

The third option on the demand side is for customers to carry a smart card, in the form of a loyalty or credit card, which is scanned at the point of sale (PoS) or near an entrance to the store. When combined with data on the customer's actual purchases, this option is the cheapest way to document customer visit frequency and shopping habits. However, the card technology can determine customer shopping habits only over time and does not capture shopper behavior during a store visit.

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[5] Such tracking is possible because smartphones are equipped with embedded sensors such as GPS, accelerometer and pairing with Bluetooth or Wi-Fi-based sensors.

[6] Starbucks Siren Order, https://www.nfcworld.com/2014/06/04/329509/starbucks-korea-lets-customers-place-orders-mobile-phone-countries-follow/

Supply Side

Most apparel stores require a high density of devices because the store’s number of items range from thousands to hundreds of thousands. The device density needed will determine which IoT option the store employs to monitor inventory and track each item on the floor, as we describe next.

For a high-density environment, passive RFID tags operating at ultra-high frequencies are the most widely available type of IoT device. A tag can be purchased for as little as $0.05; it can easily be attached to any apparel item or consumer good and then discarded after use. The emergence of *printable* RFID tags has made these IoT devices an integral part of almost every product’s packaging; there’s no need to remove and dispose of them at PoS. When attached to each item, passive RFID tags provide wall-to-wall visibility of the location of each item in real time. Each tagged item can provide unique product information that shoppers and store clerks can access at any time. Research has shown that real-time inventory visibility can allow retailers to operate with 30% less merchandise (Stelter, 2015).

A sensor designed for medium-density contexts costs, on average, about $25; each sensor is affixed to a high-cost item, is powered by an integrated battery, and transmits data to a tag reader, access point, or gateway. The various sensor types in this class have different networking capabilities based on Bluetooth, Zigbee, Wi-Fi, ultra-wideband, or optical communication link. These sensors can provide highly accurate inventory location and path-tracking information, which can be used – in combination with beacons – as digital proximity engagement platforms to enhance customers’ shopping experience at specific locations in the stores, for instance, to deliver coupons to nearby smartphones (Stanley, 2016).

Indoor GPS-based location tracking with IoT devices also requires a dedicated battery in each device. Typical low-density use is on a container, case, or pallet, which represents a certain quantity of a specific product in SCM applications. Tracking pallets from factory to distribution center (DC) to warehouse to stockroom in real time, during both transit and storage, is a key driver of logistics efficiency. These sensors range in cost from tens of dollars to several hundred dollars depending on their operating range and other specific capabilities.

IoT STRATEGY FOR VALUE CREATION

We have just shown that there is no shortage of options when it comes to IoT. There are multiple choices in terms of information throughput (bits per second) and density of devices (number per square feet) required to track each asset. The right choice among all the possible combinations is not a straightforward decision, and companies without a clear strategy can end up adopting undesirably extreme strategies. At one extreme is the company that feels pressured to stay up to date with all the new technology and ends up spending heavily just for the sake of “having it.” Such companies eventually find themselves with bloated IoT budgets that fail to improve their bottom line. At the other extreme is the company with investment paralysis induced by the overwhelming number of options and the difficulty of establishing a link between adopting one and its bottom line. Companies that are paralyzed in this way make minimal investments in IoT and are constantly waiting for a proof of concept, which usually comes from a competitor; by then, however, it may well be too late to catch up.

Enabling Capabilities and Enhancing Capabilities

As is the case with regard to any technology, developing a successful IoT strategy must be guided by business value creation. Here we provide a simple framework that can aid top management in forming such a strategy. The main idea is to categorize each IoT opportunity under consideration based on its associated capabilities and how it creates value. We distinguish between enabling and enhancing capabilities. Although an IoT initiative might involves some combination of these capabilities, it will be instructive to treat them separately. An *enabling* capability creates value by allowing the company to perform existing tasks more efficiently. For example, traffic counts can be done more efficiently with motion sensors than by hand, and inventory counts can be practically automated by using RFID tags. The enabling capabilities of IoT can also be viewed as ways of addressing imbalances that arise when product fulfillment and product information are decoupled, as discussed previously. An *enhancing* capability, in contrast, creates value through new opportunities that are unique to IoT and that would otherwise be almost unconceivable.

It is easy to identify enabling IoT capabilities because they are based on the company's current operations. Such identification is a convenient starting point before tackling the greater challenge of identifying IoT capabilities of the enhancing type. As shown in Table 1, it is also helpful to arrange IoT capabilities in terms of their main area of impact: supply, demand, or both.

[[Insert Figure 1 about here]]

Figure 1 presents an "opportunity map" that summarizes our proposed framework. Recall that different opportunities are represented by capabilities, which are classified along two dimensions. The figure's horizontal axis corresponds to *how* the capability creates value and ranges from purely enabling capabilities to those that are almost exclusively enhancing. The vertical axis represents the main area of impact, from demand to supply and including combinations thereof.

We explore this figure by starting in the upper left corner. The IoT opportunities listed there enable capabilities that affect mostly the supply side of a retail business. The most common example is RFID tags to improve inventory accuracy. Using RFID at the item level provides the retailer with real-time inventory information, as the cases of Macy's and Marks & Spencer demonstrate. Item-level RFID tagging is a high-density implementation (see Table 1), yet the value created through efficiency gains extends beyond faster and more reliable inventory counts. For instance, "phantom" stock-outs can be eliminated, misplaced items easily located, and full backroom visibility is made possible. At Macy's, cycle counts are made each month via handheld RFID readers. The key driver initially for Macy's was on-time inventory replenishment, and the practice has already improved financial and operating results (Roberti, 2016b). Similarly, weekly inventory at Marks & Spencer is taken by handheld RFID readers. This information is used to optimize merchandising by tailoring each store's inventory to specific demographics (Swedberg, 2015).

Another instance in the figure's upper left corner is anti-counterfeiting. For luxury brands, counterfeits have become a significant challenge. The availability of (and demand for) counterfeit goods erodes brand equity and the supplier's reputation while diminishing customer confidence in the product. Hence major luxury brands (e.g., Michael Kors, Gucci, Tiffany, LVMH) have formed alliances and placed RFID chips in their products so that they can be authenticated with a smartphone or handheld scanner.[7] Ferragamo has inserted RFID microchips into the soles of almost all its shoes. Such chips usually incorporate anti-cloning features that prevent others from copying the RFID chips or their contents. These capabilities are likewise of the enabling type. Figure 1's upper *right* corner shows supply-side IoT applications by which the retailer can attain previously unachievable levels of warehouse automation and supply chain optimization, which in our definition correspond to enhancing capabilities.

Building further on supply-side enhancing capabilities, one can visualize integrating the emerging technology around blockchain and digital contracts with real-time inventory data throughout the supply chain. That integration would allow retailers to track, authenticate, and receive their goods from inception of an advanced shipping notice to delivery of goods on the shelf. Retailers could use this to improve their ordering systems. Preliminary tests of such systems have already been reported (Russell, 2016).

In the demand-side (lower area) of Figure 1, enabling IoT capabilities (on the left) include targeted marketing and traffic counting; this could eventually lead to traffic path analysis as an enhancing capability (see the figure's lower right corner). In the future, advanced uses of augmented reality (AR) could drive unique customer experiences by providing digital

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[7] See https://www.businessoffashion.com/articles/fashion-tech/can-new-technologies-thwart-luxury-fashion-counterfeiters-rfid-nfc-alibaba

touchpoints (including interactive display terminals and chatbots) and by allowing for prices to be adjusted in response to real-time demand patterns. Nordstrom recently announced a five-year, $1 billion investment to customize the shopping experience and capture customer shopping behavior across channels.[8] These capabilities could have a significant impact on demand, just like RFID and inventory accuracy impact supply.

The IoT Sweet Spot

The ultimate potential impact of IoT results from its capacity to address and then transcend the challenges of omnichannel retailing. This potential is captured in our framework by those enhancing capabilities that impact both supply and demand, which we identify as the "sweet spot" in Figure 1. For instance, a proper implementation of BOPS builds on a supply-side IoT enabling capability: near-perfect tracking of inventory. Indeed, retailers reach 95% accuracy when RFID tagging is used (Hardgrave, 2016). Real-time inventory visibility also empowers the sales associate to guide customers instantly to a particular item in the store; the outcome is increased customer satisfaction and more cross-selling opportunities (Bell et al., 2014), which is thus an IoT enhancing capability. Similarly, anti-counterfeiting is a supply-side enabling capability that renders products traceable, which can also affect the demand side by increasing customers' willingness to pay. Another example is size-level replenishment. Most retailers operate with "case packs", which have a predetermined assortment of sizes.[9] Case packs facilitate handling and tracking in the supply chain; yet they create unbalanced size profiles at the stores, which reduces demand. The use of RFID and sensors facilitates size-level replenishment and so can eliminate the need for case packs, thereby becoming an enhancing capability that affects both supply and demand.

Pricing is another activity that can be enhanced by the use of IoT data, which allow dynamic pricing decisions (and limited-time discounts) on a daily basis to normalize in-store inventory

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[8] "How Fashion Retailer Nordstrom Drives Innovation with Big Data Experiments." Retrieved from https://datafloq.com/read/how-fashion-retailer-nordstrom-drives-with-innovat/398

[9] There are a few notable exceptions, such as Zara, that do not rely on case packs; see Caro and Gallien (2010).

levels. In today’s fashion-conscious world, retailers are constantly introducing new products. How should such items be priced? The retailer can use machine learning algorithms – together with demand forecasting trained on customer shopping data (collected at each store) and real-time visibility of inventory – to adopt dynamic pricing and also to estimate future demand for new products more effectively (Coresight Research, 2018).

Organizing merchandise across the planogram (store layout) and choosing the location of promotional displays can spur both traffic and conversion rate. The process of optimizing these decisions is made more efficient by IoT systems. The effect of item adjacency can stimulate impulse purchases, which account for 70% of buying decisions (Knowledge@Wharton, 2009); this, too, constitutes an enhancing capability. Moreover, studies show that an increase in the conversion rate is associated with an increase in future traffic growth (Perdikaki et al., 2012).

The full potential of IoT is being exploited by Inditex/Zara, which brings products from factory to shelf in a matter of weeks (Caro, 2012). Zara has, for the last three years, used RFID for SCM optimization and in-store inventory management.[10] Real-time inventory visibility was key to Zara’s strategic omnichannel objectives, and now it uses RFID technology for purposes beyond operational efficiency; these purposes include assortment planning and inventory allocation worldwide as well as improving the individual customer’s experience in each of its stores.

The framework just described should not be seen as a single-shot attempt but rather as a gradual discovery process. Many case studies – and also the authors’ own experience – have demonstrated that, although the immediate benefits of enabling capabilities are attractive, the more enduring value tends to come from unforeseen opportunities (i.e., enhancing capabilities) that are realized once the technology is adopted and the resulting data are fully understood. In other words, enabling capabilities are expected benefits that could also be realized by a competitor, whereas enhancing capabilities require insider knowledge and thus can be the

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[10] See http://rfid24-7.com/2016/03/17/inditex-continues-rfid-rollout-to-2000-zara-locations

source of a longer-lasting competitive edge. In the words of Macy’s senior vice-president of logistics and operations: “You find this natural ability to expand and do additional things that have a big impact on sales and profitability” (Roberti, 2016b). Because enhancing capabilities are by definition new and unforeseen, investors may view them as being too risky. To mitigate that risk, the retailer should search for opportunities mainly in the sweet spot illustrated by Figure 1.

IMPLEMENTATION CHALLENGES

The framework in Figure 1 reflects two fundamental tenets of an IoT strategy. First, IoT initiatives should be evaluated by accounting for their immediate benefits (enabling capabilities) and also for their potential value (enhancing capabilities). Second, the potential value comes from opportunities that bridge the gap between supply and demand – a mismatch that omnichannel retailing has exacerbated. The question remains of how best to *evaluate* a strategy’s immediate benefit and, especially, its potential value. A simple rule of thumb is to expect the enabling-driven benefits of an IoT initiative to be almost immediate, with a payback of less than one year. If that does not occur, then the benefits due to enhancing capabilities should make up for it within about five years or less.

Not all retailers are equally predisposed to implementing IoT devices. Retailers that sell their own brand can easily set up RFID tagging, but those that stock private labels and/or sell items from multiple brands face greater challenges. Namely, using RFID in such cases requires either a mandate issued to suppliers or the tagging of items at the retailer’s distribution center – or, as a last resort, in the backroom of each store.

In terms of investment, the total cost of ownership for deploying and consuming the data sourced by IoT devices depends mainly on the amount and frequency of the data that they generate (see Table 1). It is noteworthy that the cost of silicon, which is the main raw material for all of these IoT devices, has fallen by more than half over the last decade even as this substance has become more versatile.[11] This trend is expected to continue over the next decade, reducing not only the cost but also the size of these devices.

Finally, there are privacy and security concerns with IoT devices that include authentication, malware, spoofing, and cryptographic attacks. A well-publicized pilot program by Benetton to introduce RFID in its stores created some public backlash when privacy groups called for a boycott because they feared the chips could be used to track people wearing the clothes (Violino, 2003). This event happened several years ago. The recent generation of RFID tags have the facility to be "killed", which essentially renders the device useless at PoS. Moreover, a company can secure the IoT data collected in-store by choosing an "on-premise" option, under which all data are collected and maintained locally in fully decoupled subnets. However, cloud-based networks require additional security measures.[12]

Firms that overcome these challenges and that embrace both the enabling and enhancing capabilities of IoT should be able to pursue a successful IoT strategy and avoid the undesirable extremes of investment paralysis and overspending. The adoption of an adequate IoT strategy will help such firms bridge the gap between information provision and product delivery that has widened since the introduction of omnichannel retailing.

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[11] AssetMacro Silicon 98.5% Price Charts: https://www.assetmacro.com/global/commodity/silicon-price

[12] The use of facial recognition and biometric data is an active area of legislation at both the state and federal level. It is our intention here to merely outline the possibilities of using sensory data in retail applications.

REFERENCES

Bell, D. R., Gallino, S., & Moreno, A. (2014). How to win in an omnichannel world. *MIT Sloan Management Review, 56*(1).

Caro, F. (2012). Zara: *Staying fast and fresh*. Business case, The Case Center, reference number 612-006-1.

Caro, F., Gallien, J. (2010). Inventory Management of a Fast-Fashion Retail Network. *Operations Research*, 58(2), 257–273.

Columbus, L. (2017). Internet of things will revolutionize retail. *Forbes*, 19-Mar-17. Available at https://www.forbes.com/sites/louiscolumbus/2017/03/19/internet-of-things-will-revolutionize-retail/. Last accessed March 6, 2018.

Coresight Research (2018). *Dynamic Pricing: Hard to Compete with AI on Pricing.* Available at https://www.fungglobalretailtech.com/research/dynamic-pricing-hard-compete-ai-pricing/. Last accessed March 8, 2018.

Finkenzeller, K. (2015). *RFID Handbook: Fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication* (3rd ed., trans. D. Müller). West Sussex, UK: John Wiley & Sons, Ltd.

Fisher, M.L. (1997). What is the right supply chain for your product? *Harvard Business Review*, March–April.

Hardgrave, B. (2016). *Laying the foundation for an omnichannel strategy with RFID*. Paper presented at the meeting of RFID Journal Live! Europe Conference, London, UK.

Knowledge@Wharton (2009). *Not on the List? The Truth about Impulse Purchases*. Available at http://knowledge.wharton.upenn.edu/article/not-on-the-list-the-truth-about-impulse-purchases/. Last accessed March 8, 2018.

Kressmann, J. (2017). Retailers missing out on benefits of in-store pickup. *eMarketer*, 9-Apr-17. Available at https://retail.emarketer.com/article/retailers-missing-on-benefits-of-in-store-pickup/58ae21389c13e50de431c9e1. Last accessed March 6, 2018.

Krotov, V. (2017). The Internet of Things and new business opportunities. *Business Horizons, 60*(6), 831-841.

Mou, S., Robb, D.J., DeHoratius, N. (2017). Retail store operations: Literature review and research directions. *European Journal of Operations Research*, 265, 399-422.

Parris, S., Spisak, A., Lepetit, L., Marjanovic, S., Gunashekar, S., & Jones, M. M. (2015). *The digital catapult and productivity: A framework for productivity growth from sharing closed data*. Research Report RR-1284-DC, RAND Europe.

Pelino, M., & Gillett, F.E. (2016). *The Internet of Things heat map*. Forrester Research.

Perdikaki, O., Kesavan, S., & Swaminathan, J. M. (2012). Effect of traffic on sales and conversion rates. *Manufacturing & Service Operations Management, 14*(1), 145–162.

Roberti, M. (2016a).*The business case for RFID in retail apparel*. Paper presented at the meeting of RFID Journal Live! Europe Conference, London, UK.

Roberti, M. (2016b). Macy's to RFID-tag 100 percent of items. *RFID Journal*, October 12.

Russell, M. (2016). World's first cotton shipment uses blockchain system. *Just-style.com*, November 1.

Stanley, T.L. (2016). 5 Trends That Are Radically Reshaping Shopper Marketing. *Adweek*, June 19.

Stelter, S. (2015). *Understanding real-world ROI for RFID in retail*. White paper, ChainLink Research: Newton, MA.

Swedberg, C. (2015). Marks & Spencer expects to achieve 100 percent RFID tagging by 2017. *RFID Journal*, May 11.

Tyo, R. A. (2006, November). *Connecting the real-world environment to the digital backbone: RFID & wireless sensor networks*. Paper presented at the meeting of Intel, 3rd Asia Academic Forum, Kuala Lumpur, Malaysia.

Verhoef, P., Kannan, P.K., & Inman, J. (2015). From Multi-Channel Retailing to Omni-Channel Retailing. *Journal of Retailing* 91(2) 174-181.

Vermesan, O., Friess, P., Guillenmin, P., Gusmeroli, S., Sundmaeker, H., Bassi, A., Soler Jubert, I., Mazura, M., Harrison, M., Eisenhauer, M., & Doody, P. (2011). Internet of Things Strategic Research Roadmap. In *Internet of Things Global Technological and Societal Trends*. River Publishers, Aalborg, Denmark.

Violino, B. (2003). Benetton Explains RFIC Privacy Flap. *RFID Journal*, June 22.

World Economic Forum (2017). *Shaping the Future of Retail for Consumer Industries*. Available at www3.weforum.org/docs/IP/2016/CO/WEF_AM17_FutureofRetailInsightReport.pdf. Last accessed Feb 23, 2018.

Table 1: Demand-side and supply-side IoT thing types.

Demand		**Supply**	
IoT Thing Types		IoT Thing Types	
High throughput:	*Camera network*	High density:	*Passive RFID tags-UHF* *$0.05<price<$0.25*
Medium throughput:	*Smartphone*	Medium density:	*Bluetooth, Wi-Fi, optical* *$5<price<$100*
Low throughput:	*Smartcard chip*	Low density:	*GPS & telemetry* *$10<price*

Figure 1: Opportunity map for an effective IoT strategy.