IoT-Based Inventory Tracking in the Pharmaceutical Industry

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Abstract

Inventory visibility has been a primary concern for corporate supply chains for decades. Utilizing inventory location and time data is particularly important for pharmaceutical companies, as is the sponsor, that have an ethical and legal responsibility to protect consumers from risky pharmaceutical products in the market. Until recently, pharmaceutical companies have had to rely on archaic, cumbersome methods to track or count inventory units. These processes created inaccuracies and mismanaged inventory, leading to unnecessary product waste, returns, and consumer risk. However, technological advancements have created platforms to track physical goods characteristics using wireless network systems in real-time. This technology, commonly referred to as the Internet of Things (IoT), provides a potential solution for pharmaceutical companies to manage and protect pharmacy inventory levels, while maintaining consumer protection and brand integrity. This study analyzes the economic and practical implications of implementing an IoT inventory visibility solution within the sponsor's supply chain to mitigate consumer risk and existing corporate financial waste streams. Through existing technology research, real-world device experimentation, and cross-functional supply chain analyses, the team proposes a Bluetooth technology IoT network infrastructure and business implementation approach for the sponsor's inventory visibility needs.

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1 Introduction

1.1 The Sponsor

The sponsor company for this project is a multi-billion dollar pharmaceutical manufacturer. It's supply chain structure creates natural barriers to customer-level inventory visibility. After manufacturing is complete, the sponsor ships its products to a distributor, who assumes financial ownership and delivery to customers (hospitals, clinics, pharmacies, etc.). This downstream supply chain can involve numerous complexities, such as inter-warehouse shipments, third-party delivery, and last-mile delivery to and between customers. While the distributor or customer may own the inventory after manufacturing, the sponsor still assumes a wide range of product responsibility due to the legal obligations of drug manufacturers in the United States. Additionally, it is still financially responsible for any product returns due to shelf-life expiration, quality concerns, or mishandling in the field. Figure 1.1 depicts the high-level supply chain network design from manufacturing to the end consumer.

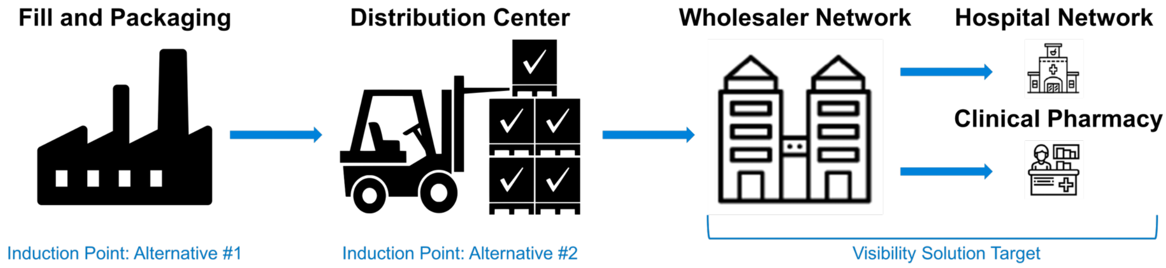

Figure 1.1: Sponsor Company's Supply Chain Network

The wholesaler network is used to store products closer to the end customer and manage logistics and distribution challenges. As products transition from the distribution center to the wholesaler, a change in inventory ownership occurs. At that point, the sponsor no longer has ownership of the product and, without the use of IoT tracking technology, loses visibility of movement and storage within the wholesaler. The only other information that the sponsor receives is how much product leaves the wholesaler and when. The "visibility solution target" depicted in Figure 1.1 is the main focus of the implementation of IoT technologies and sensors for customer level visibility. While the sponsor is still in possession and ownership of the pharmaceuticals, two induction points exist at the manufacturing facility and distribution center that offer opportunities to implement technology to track products.

Per the sponsor, the supply chain can be segmented into smaller, trial networks for use case implementation and testing which will allow the team to internalize supply chain disruptions, limit unknown variables, and impact fewer stakeholders. The goal of this segmented approach is to build the business case for stakeholder buy-in and involvement and to address the scope and feasibility of inventory visibility across the United States. The team will build the foundation for the project through limited test case implementation. As the project scales, the inclusion of manufacturing and filling through end customer will require stakeholder integration and change management techniques.

1.2 Problem Motivation and Background

The sponsor had previously deployed an internal team to test a potential on-cap solution for products' location tracking, temperature and condition information, and end usage data. The internal team's initial intent was to generate a similar approach to vial usage with an on-cap solution. The team faced issues with current market technologies available which included size and form factor for an on-cap solution coupled with the regulations surrounding adjustments to product packaging. Ultimately, data acquisition and analysis from the wholesaler would circumvent the need for a technology solution until a better approach was devised.

The sponsor's supply chain continued to suffer from unnecessary product waste driven by customer inventory mismanagement and out-of-date product returns. The contradiction between product ownership and lack of inventory visibility leaves the sponsor prone to product losses it is unable to anticipate nor investigate.

To minimize these costs and help customers adequately manage their inventory levels, the sponsor purchases data from external third parties. This data includes location and time information for inventory as it is received and shipped by the distributor. Unfortunately, it does not include any visibility to inventory location nor status beyond the shipment at the distributor. This leaves the sponsor blind regarding its downstream inventory status at the customer level. Compiling the sponsor's supply chain costs is the multi-millions of dollars wasted on expired product returns resulting from inventory mismanagement at the customer level.

The company's largest opportunity to reduce costs through enhanced customer inventory visibility is by implementing product tracking technology. Moreover, by utilizing some form of Internet of Things (IoT) sensing technology, The sponsor can obtain real-time visibility on each of its finished products' locations and, potentially, temperature. In order to be effective, this type of sensing technology must be physically integrated within the sponsor's packaging design. Additionally, the technology must be able to meet the sponsor's financial, technological, and practical needs to ensure sustainable implementation.

1.3 Problem Definition

The project's goal is to identify a feasible type of IoT technology, test its use across a small, controlled segment of the sponsor's supply chain, and analyze the results to provide a proof-of-concept business case for full-scale implementation. The final solution is hypothesized to be a combination of NB IoT technologies and Mesh Networking as seen in Figure 1.2.

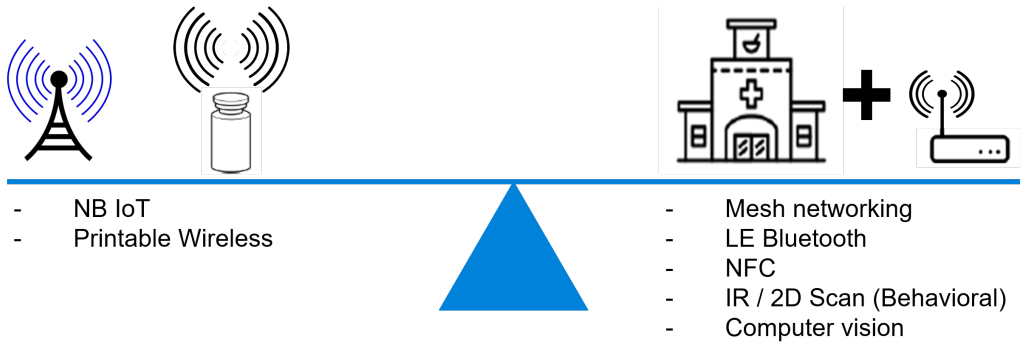

Figure 1.2: Technology Center of Gravity

This solution for inventory tracking may be the first step to a future scale up solution that encapsulates the sponsor's supply chain requirements. A granularity of data and information is defined that must be obtained to meet the desired business case of inventory location and tracking to substantiate the proposed investment. Later iterations of this solution will be needed to incorporate temperature and conditional information of the product, which is currently out of scope for this study. The purpose of the solution for this problem is to enable a foundation for the sponsor to get closer to the patient. Environmental conditions of the sponsor's products, including temperature and humidity, are an important future step as the products are safe only when maintained within certain parameters dependent to the specific drug.

1.4 Scenarios of Analysis

The sponsor's supply chain can be segmented into different distribution channels to provide clarity and opportunity during testing and validation phases of the project. Dividing the entire network into scenarios provides different advantages and disadvantages by segmentation and potentially a technology solution. Sections 1.4.1, 1.4.2, and 1.4.3 detail the differences in the scenarios for consideration during implementation and scale-up, each of them requiring different levels of relationship management and stakeholder engagement.

1.4.1 Limited End-to-End Supply Chain Scenario

The limited end-to-end supply chain trial network was used early in the learning phase of the project to gather data and information around feasibility and transparency of inventory movement from the distribution center through the wholesaler network, and to the end consumer (hospitals and pharmacies). Figure 1.3 represents the limited end-to-end supply chain network that the sponsor used during the business case development phase of the project.

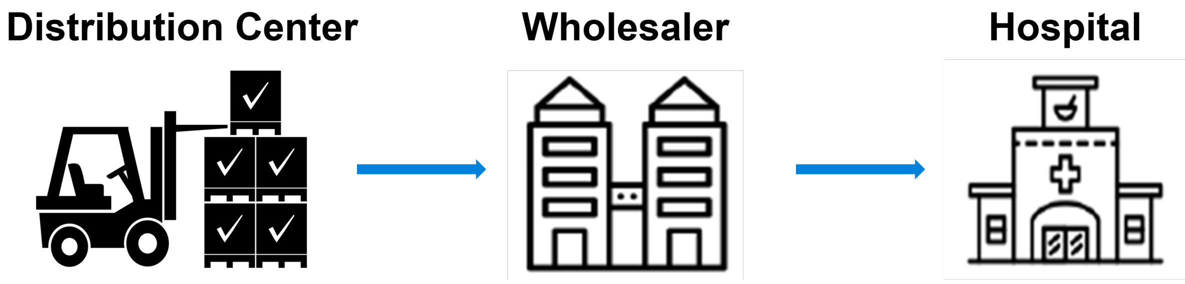

Figure 1.3: Limited End-to-End Supply Chain Network

The advantages of the limited end-to-end supply chain trial scenario include fewer stakeholders, control at the distribution center, and key feasibility learning in the latter half of the entire network. As determined by the sponsor, this trial scenario does not present any foreseeable challenges during testing.

1.4.2 Extended End-to-End Supply Chain Scenario

The extended end-to-end supply chain incorporates the manufacturing facility into the limited end-to-end supply chain previously mentioned. Figure 1.4 depicts the entirety of the extended network that will be used for scale-up in future phases of the project testing and launch.

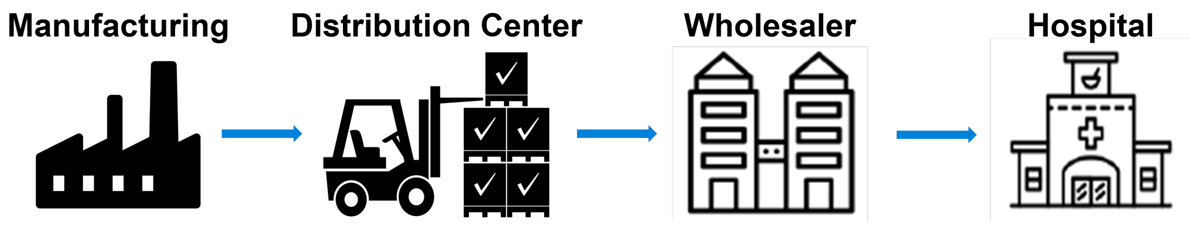

Figure 1.4: Extended End-to-End Supply Chain Network

The advantages of the extended end-to-end supply chain include those from the limited end-to-end scenario as well as being more representative of the final state of implementation. Potential challenges that could arise during this scenario include adding additional stakeholders and introducing a complex induction point at the manufacturing level.

1.4.3 Clinical Supply Chain Scenario

The clinical supply chain is the last segmented supply chain scenario for testing and launch. This opportunity includes a pre-determined wholesaler with a strong relationship with the sponsor and the end consumers that is facilitated by a specialist team of pharmacists: Company Y. Figure 1.5 shows the scenario with the manufacturing facility and distribution center collectively represented as "The Sponsor."

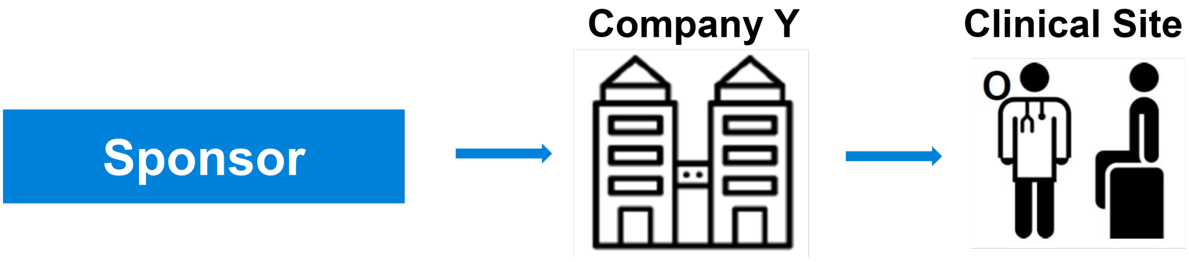

Figure 1.5: Clinical Supply Chain Network

The advantages of the clinical supply chain trial scenario are as follows: the wholesaler is a willing partner in the inventory project, minimal stakeholder engagement is needed to integrate at this stage, the sponsor has brand recognition in this network, and the final induction point could be moved to the wholesaler level rather than controlled by the sponsor. Achieving a return on the investment poses a significant challenge in this network. The clinical supply chain already presents opportunities for better inventory visibility based on structure, relationship, and production of branded pharmaceuticals.

In summary, the sponsor's complex supply chain structure and dependency upon third party data promote a lack of inventory visibility beyond its first tier of customers. Ultimately, this capstone will be an evaluation of viable IoT technology to identify the most appropriate solution to maximize financial return while minimizing supply chain disruptions and delivering inventory tracking capabilities to the business.

2 LITERATURE REVIEW

2.1 PHARMACEUTICAL INDUSTRY

The pharmaceutical industry is under immense pressure to meet the needs of the aging patient population. Specifically, it must deliver better outcomes in a cost-efficient, timely manner. By the year 2035, it is estimated that the total population over the age of 65 will surpass the total population under the age of 18 in the United States. The Baby Boomer generation is aging and reaching a stage in life (age 65) where the average unique prescriptions per consumer rises from 3.15 to 8.85. Moreover, the need for efficient modes of drug delivery is heightened exponentially (Watanabe, 2019). Data from the US Census Bureau and other government-supported entities state that the current population ages 65 and above represents approximately 16.9% of the population and will grow to approximately 22% in the next thirty years (Statista 2019). Figure 2.1 represents the increasing nominal spend on medicines in the United States from 2002 to 2018. With this trend, the value of real-time, accurate information aggregated back to the manufacturer is necessary to sustain industry growth.

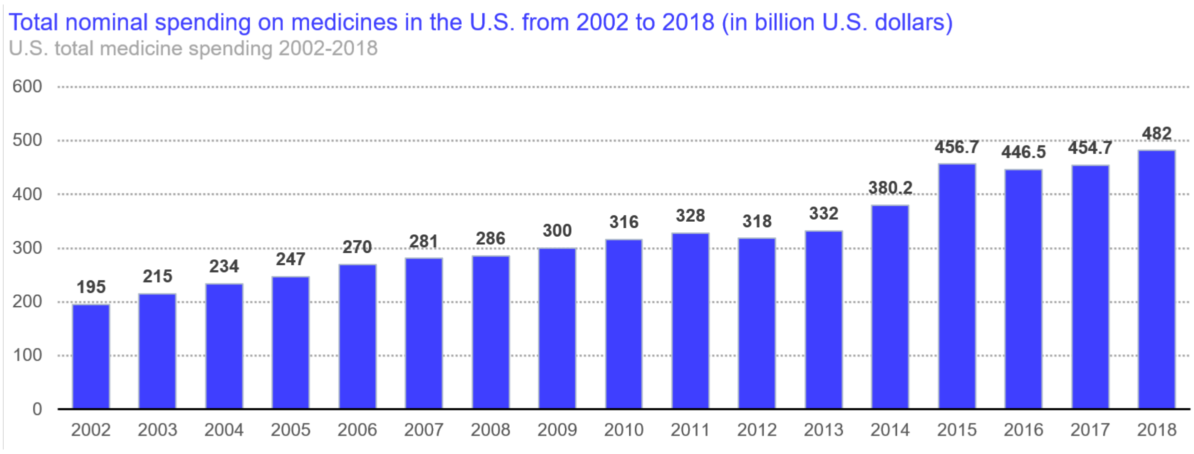

Figure 2.1: Total Nominal Spending in the US on Medication 2002-2018 (Statista, 2019)

The pharmaceutical industry can be segmented and characterized by the branding of each drug as well as the type of substance being created. Pharmaceuticals are manufactured in the form of branded drugs or generics that can also be derived by forming different size molecules or utilizing different biologic processes (Singh, 2005). Branded drugs are typically more specialized and require prescriptions for the end user while generics are over the counter drugs that can be used without prescription. Packaging requirements also differ between branded and generic drugs which impacts the form factor and available space for an IoT device solution for tracking.

Figure 2.2 depicts the change in prescriptions and consumer behavior from branded to generics supplements. One of the key factors in the transition to consumers preferring generics over branded drugs is price point, as generics offer a cost-effective alternative to branded drugs (Hunt III et al., 2019). During the phase of exclusivity, pharmaceutical manufacturers' branded drugs are priced higher to recover research and development costs sunk into producing the new drug. After the patent life expires, drugs can be produced as generics and offered at lower price points. Figure 2.3 depicts the share of revenues from 2005 to 2018 of branded drugs versus generics. The portion of prescriptions being filled shifting towards generics while the proportion of revenues generated by generics remains relatively consistent.

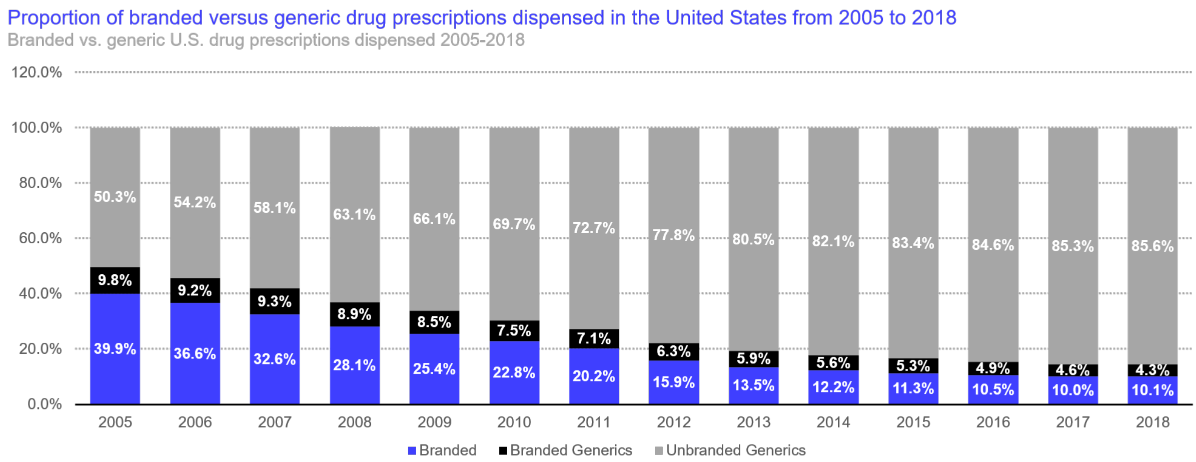

Figure 2.2: Proportion of Branded v Generic Prescriptions in the US 2005-2018 (Statista, 2019)

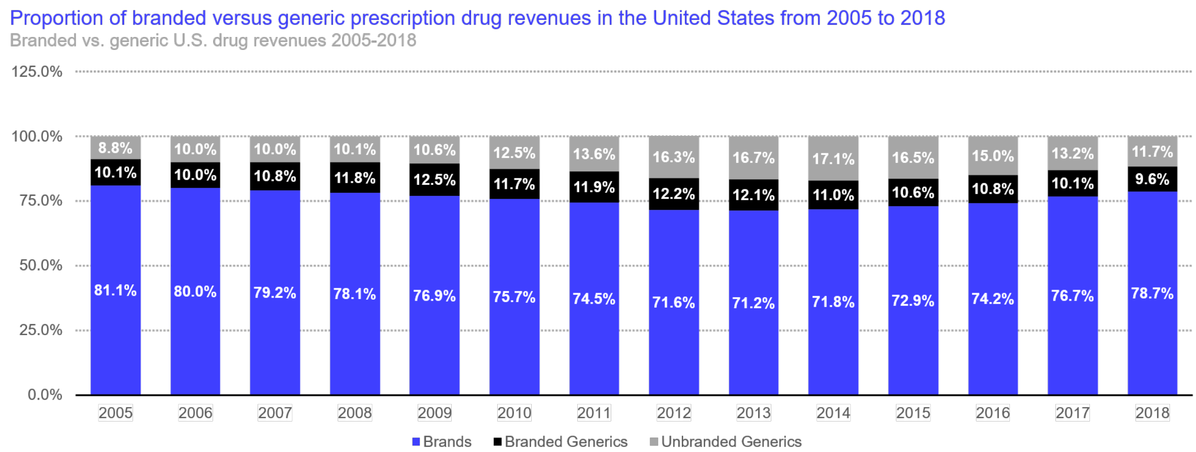

Figure 2.3: Proportion of Branded v Generic Revenues in the US 2005-2018 (Mikulic, 2020)

The push to having backward visibility in the pharmaceutical supply chain is needed for the integration of information from the consumer, through the distributor or wholesaler, to the manufacturer (Morris, 2019). Molecular or biological manufacturing processes of drug substances require different lead times as well as different specifications for transportation and packaging. Visibility throughout the supply chain would provide insights back through manufacturing to address the specific requirements. Speed to market and proper inventory management principles allow pharmaceutical manufacturers to meet the ever-changing demands of consumers. With generics being sold over the counter without prescription, the volume of pharmaceutical sales could follow a trend similar to the change in demand from branded to generic. Having real-time, accurate inventory management will give pharmaceutical companies, such as the sponsor, the ability to adapt and be agile in the market place.

2.1.1 Structure of Pharmaceutical Supply Chains

The stakeholders involved in a pharmaceutical supply chain include research and development, manufacturers, warehouses, transportation, wholesale distributors, retail pharmacies, healthcare providers, and end consumers or patients. When it comes to manufacturing, drug manufacturing is often done in batches or campaigns to build inventory over a rolling time period (Shah, 2004). This batch style manufacturing does not lend itself to responsiveness to market or consumer demand changes. Furthermore, it can lead to waste throughout the entire supply chain, most found in inventory holding. Companies in the pharmaceutical industry are interested in inventory holding because it ties up working capital that can be used elsewhere in the business, and strategic inventory positioning is an important analysis towards reducing inventory costs (Krishnamurthy & Prasad, 2012).

Unlike the scenario depicted in Section 1.1, in some instances manufacturers ship directly to healthcare providers or retail pharmacies. The multi-channel distribution strategies are dependent on the relationship between the pharmacy and manufacturer (Iacocca & Mahar, 2019). Figure 2.4 depicts a pharmaceutical supply chain structure from research and development to the end consumers without the wholesaler distributor in the distribution network.

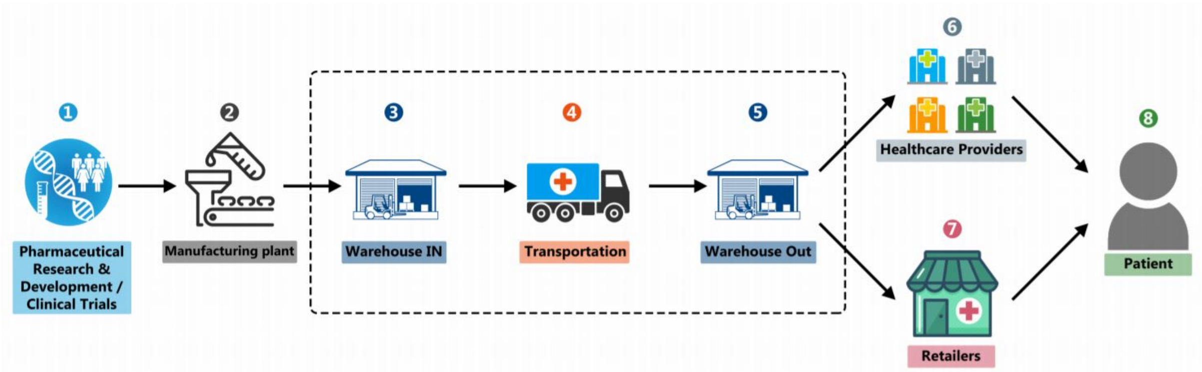

Figure 2.4: Pharmaceutical Supply Chain Design (Khezr et al., 2019)

However, in most cases, the manufacturer passes the finished product through their distribution network to a wholesale distributor. The wholesale distributor takes ownership of warehousing, aggregating, and distributing inventory to the final destination accordingly. This wholesaler distribution channel accounts for 86.6% of annual pharmaceutical purchases by pharmacies (Beier, 1995). Supply chains must be structured to coordinate with the core business processes of end consumers. The network is historically built on relationships between wholesale distributors and pharmacy management (Singh, 2005).

Understanding the characteristics, including end-of-life thresholds, of pharmaceutical products and their demand cycle uncertainties should influence appropriate inventory policies. As complexities and tiers of supply chain networks become more diverse and increase the length of distribution, pharmaceutical manufacturers become more susceptible to risks and counterfeiting (Aigbogun et al., 2015). The tiered nature of pharmaceutical supply chain networks, coupled with the dynamic nature of consumer behavior in the industry, without visibility brings about risks of true consumption and usage beyond the purchasing and inventorying policies set in place. At the end of the network, the difference in purchasing trends by pharmacies and consumption or point-of-sale information to the end consumer creates the opportunity for reverse logistics with buy-backs at a product's end-of-life. product (Singh, 2005).

2.1.2 Wholesaler Distributors in Pharmaceutical Supply Chains

Wholesaler distributors play a critical role in the delivery of pharmaceuticals to pharmacies around the world. The key responsibilities at this stage in the supply chain are demand and inventory aggregation, in addition to standard warehousing operations. The pharmaceutical industry is highly regulated, adding complexity to a distribution workflow. Wholesale distributors are responsible for managing appropriate inventory levels to service all of their consumers while giving their suppliers notice on current inventory levels to trigger production and delivery from manufacturers (Shah, 2004). In a study conducted surrounding quality metrics for primary wholesaler distributors, the top three attributes were 1) delivery within twenty-four hours of order placement, 2) electronic ordering, and 3) consistent daily delivery times (Beier, 1995). With two of the top three metrics focused on delivery, wholesalers attempt to anticipate pricing changes that influence demand. This leads to pre-emptive large order requests from the manufacturers (Shah, 2004). A study conducted on wholesaler distributor inventory policies concluded that pooling inventory at the distributor level, instead of disparate pharmacy locations, can improve entire system performance in terms of finances and flexibility (Iacocca & Mahar, 2019).

As products change ownership at the point of exchange from manufacturer to wholesaler, pharmaceutical companies tend to lose sight of their inventory. Although it has not reached the point of consumption, the inventory is out of their hands from a control perspective. Some data is shared between wholesale distributors and manufacturers on inflows and outflows of product from warehouses, but it does not give manufacturing companies a good sense of consumer demand and usage. This lack of transparency offers opportunities for manufacturing and inventorying inefficiencies to be realized throughout the industry.

2.1.3 Reverse Logistics in Pharmaceutical Supply Chains

Reverse logistics in the pharmaceutical industry, triggered by the end of life of a drug, materialize in the form of recalls or inventory buy-backs. This study is mainly focused on the frequency of inventory buy-backs and the root causes of pharmaceuticals reaching their end-of-life while on the shelf. The industry faces a common dilemma of carrying high levels of finished goods inventory, which exacerbates the issue of drug expiration and required buybacks (Singh, 2005). Appropriate inventory management principles and inventory turn procedures may provide a potential solution to one of the root causes of this reverse logistics requirement.

Any return implies a logistics route to be defined, financial impact to be recorded, disposal of the drugs in a regulated environment, potential legal implications, and reconciling of all inventory across the network (Singh, 2005). The environmental risk associated with improper disposal of pharmaceuticals is one of the key drivers of the need for reverse logistics programs (de Campos et al., 2017). Positive customer perception is also necessary for pharmaceutical manufacturers to stay competitive. Taking the appropriate steps toward limiting the environmental impact helps organizations maintain a positive image. Companies rely on brand recognition and speed-to-market to stay relevant in the industry. In contrast, research and development activities, through manufacturing practices, take years to formulate a new product.

With the various implications, especially legal and regulatory, of end-of-life or end-of-use drugs to pharmaceutical companies, the importance of monitoring the patterns related to inventory expiration are crucial for implementing appropriate inventory principles. Without visibility as to product location and timing of consumption, pharmaceutical manufacturers are at the mercy of pharmacies around the country to maintain a first-in-first-out (FIFO) methodology to turn inventory and ensure drugs are being used in their respective life-cycles.

2.2 Healthcare Pharmaceutical Inventory Processes

Inventory systems in the healthcare setting have adopted operational management principles over the years but have relied heavily on stakeholder management and relationships to build internal processes. Some organizations have started moving toward using supply chain management inventory policies to determine inventory levels and ordering processes.

Studies suggest that, historically, inventory management and ordering policies were typically driven by political and experience-based care givers or managers rather than through data analysis and policy (de Vries, 2009). In an typical supply chain setting, roles are defined and procedures for proper inventory management that have few stakeholders involved in the decision-making process. In the healthcare industry, multiple stakeholders are involved with different levels of perception regarding what constitutes quality service and appropriate inventory levels from nurses, to doctors, to pharmacists, and financial analysts (de Vries, 2009). Healthcare professionals maintain a deep-rooted sense of the need to hold excess inventories to avoid stock outs given the dire consequences to patient care.

2.2.1 Hospital Pharmacy Inventory Processes

Hospital pharmacies tend to face higher demand volatility in comparison to retail pharmacies and greater internal stakeholder pressure to hold inventory based on their environment of patient movement and employee involvement (de Vries, 2009). The consequences of inventory stock outs in a hospital setting are greatly heightened when patients have life-threatening diseases. In a study conducted by the *Journal of Business Logistics*, 43.8% of respondents used judgement or experience to set safety stock levels (Beier, 1995). This is exacerbated by physicians' and providers' willingness to switch from branded to generic therapies, influenced by their product loyalty and historical treatment success rates (Schneller & Smeltzer, 2006). Figure 2.5 depicts the influence of stakeholders and perception on the overall inventory management process. Without proper inventory management practices for ordering and holding stock, hospitals can lose sight of their total inventory cost (including ordering, carrying, and holding costs).

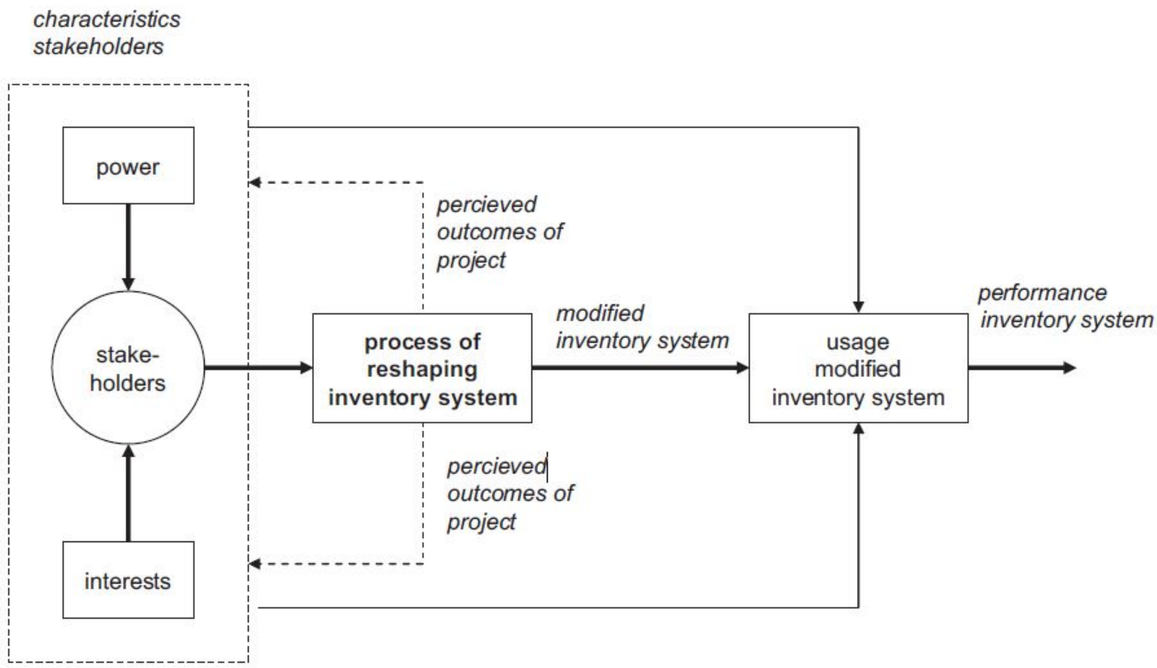

Figure 2.5: Hospital Inventory Management (de Vries, 2009)

Hospital supply chain networks can be characterized as having external and internal distribution networks. Complexities arise due to the multitude of products that hospital pharmacies handle coupled with the effect of the pharmacy's middle-man role between hospitals and patients. The pharmacy is tasked with the appropriate allocation of products to the necessary units (Rivard-Royer et al., 2002). Not only do hospitals have to manage the inventory coming into the building and pharmacy from vendors, but another level of inventory management exists within the hospital as to where the pharmaceuticals are distributed. The complexity of hospital pharmacy inventory management is detailed in Figure 2.6 and shows the growing number of final nodes that the pharmaceutical can be distributed to internally.

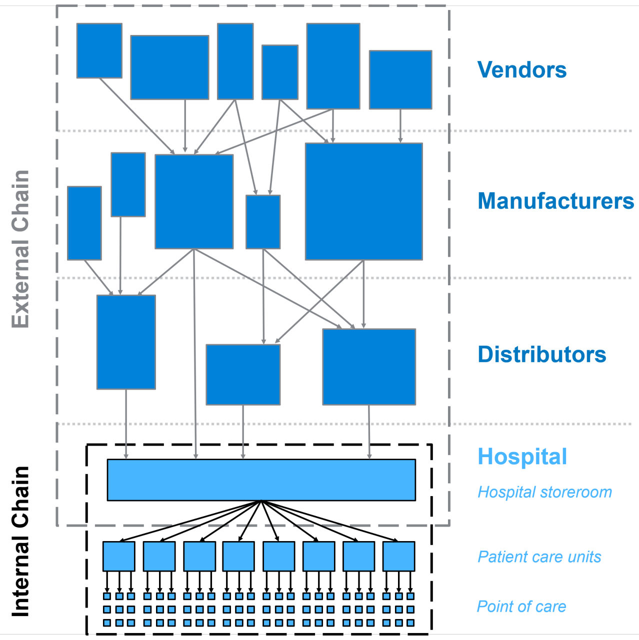

Figure 2.6: Hospital Supply Chains (Rivard-Royer et al., 2002)

Hospital inventory systems face constraints regarding demand forecasting, purchasing, receiving, handling, replenishment operations, distribution, and inventory control. The level of these constraints varies given the unit or subsidiary within the hospital (Lapierre & Ruiz, 2007). Given the intricacies of stakeholder requests and process involvement, inventory management policies are managed by hospital networks on a case-by-case basis based on prior performance and local expertise levels.

2.2.2 Retail Pharmacy Inventory Processes

Retail pharmacies face demand uncertainties based on complex factors influencing their consumers. Demand volatility, coupled with minimal inventory planning processes or software utilization, has lead to a bullwhip effect as the volatility propagates back through the supply chain (Papanagnou & Matthews-Amune, 2018). Minor fluctuations at the retail level can lead to larger implications at the manufacturer level, depending on the level of risk and the reaction by intermediaries within the network. Figure 2.7 shows the demand volatility for a generic over the counter drug at a retail pharmacy over the span of 130 weeks.

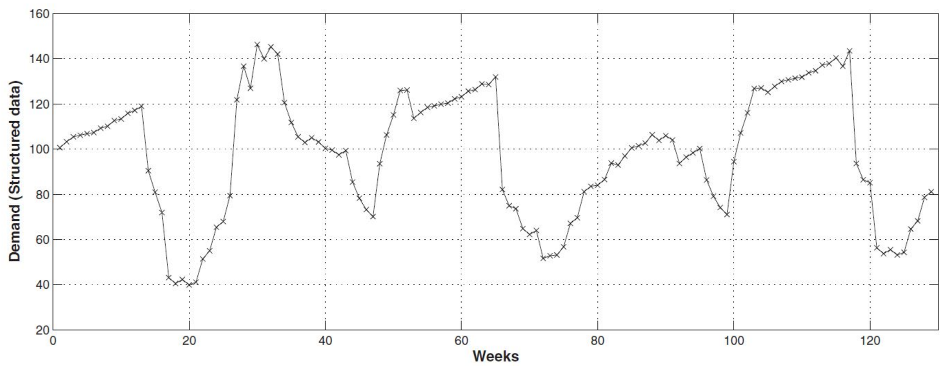

Figure 2.7: Example Over the Counter, Generic Drug Weekly Demand (Papanagnou & Matthews-Amune, 2018)

Pharmacies need the ability to forecast demand accurately and implement a standard ordering policy, usually derived from an economic order quantity (EOQ) (de Vries, 2009).

2.3 Internet of Things Technology

Sensors are physical electronic devices capable of converting non-electronic inputs into electronic signals (Holdowsky et al., 2015). In turn, this electronic signal is used to create information to drive action or change. The aggregated connection of these sensors through some sort of wireless connection is commonly known as the Internet of Things (IoT). As sensing and computing technology continues to progress, the fundamental factors driving sensor deployment have improved: price, capability, and size (Holdowsky et al., 2015). As shown in Figures 2.8 and 2.9, since 1992, sensor prices have dropped 93% and microprocessor clock speeds have increased more than 99% (Holdowsky et al., 2015). These advancements are expanding the range of technological capabilities and applications for IoT sensing.

Figure 2.8: Sensors Prices on the Decline Over Last 25 Years (Holdowsky et al., 2015)

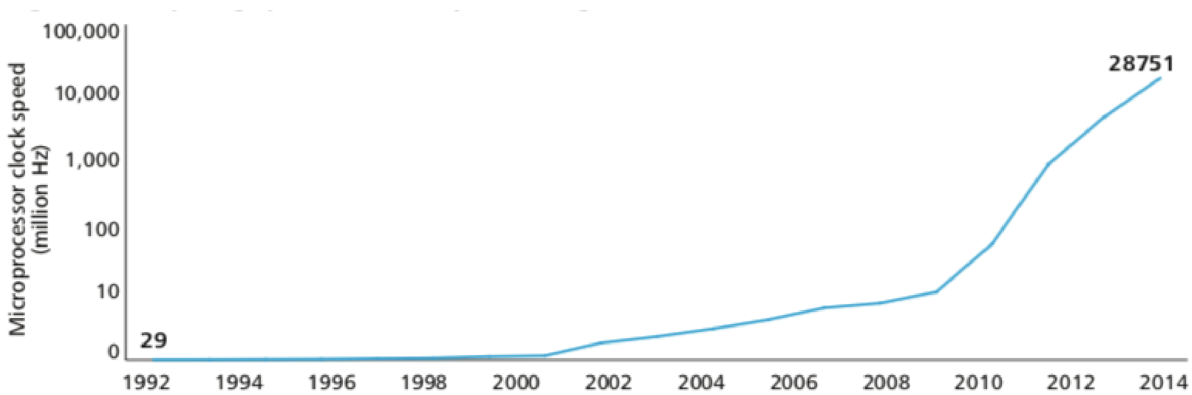

Figure 2.9: Computing Speed Continuously Increasing (Holdowsky et al., 2015)

In order to aggregate, retrieve, and analyze the signals and data produced by these sensors, the devices must be connected to a network. Typically, sensors are connected to networks using gateways, routers, or other devices (Holdowsky et al., 2015). Generally speaking, the type of network design required must be selected based on three critical criteria: data transfer rates, energy requirements, and the required graphical coverage range. In large part, data rates have significantly increased since 2002. Projected network data rates in 2020 are 1 Gbps and above, while 2002 rates were as low as 2 Mbps. Moreover, internet transit prices in the United States have decreased from $120/Mbps in 2003 to $0.63/Mbps in 2015 (Holdowsky et al., 2015).

Collectively, the technological innovation of sensors and wireless network infrastructures has enabled staggering increases in the number of connected devices. Globally, the total number of connected devices has increased from 0.5 billion in 2003 to 42.1 billion (projected) in 2019 (Holdowsky et al., 2015). This exponential device growth is likely to continue as industry trends demand increased data visibility and analysis, while technology consumers continue to demand faster network configurations. The remaining sections of Chapter 2 detail the most common tracking technology platforms across a variety of industries as well as the relevant advantages and disadvantages of each platform as it relates to the sponsor's pharmaceutical application.

2.3.1 Narrow-Band IoT Technology

One common type of IoT technology infrastructure design is Narrow-Band (NB) IoT. NB IoT is designed for portable devices to leverage ubiquitous carrier networks. The infrastructure is designed to allow a significant number of devices to operate within a 200 MHz spectrum range. NB IoT devices are attractive due to their improved indoor coverage, low power consumption, low device cost, and massive connection capacity (Huawei, 2016). The low device costs delivered by NB IoT devices is critical. Figure 2.10 compares the average cost of a NB IoT device relative to comparable IoT network devices.

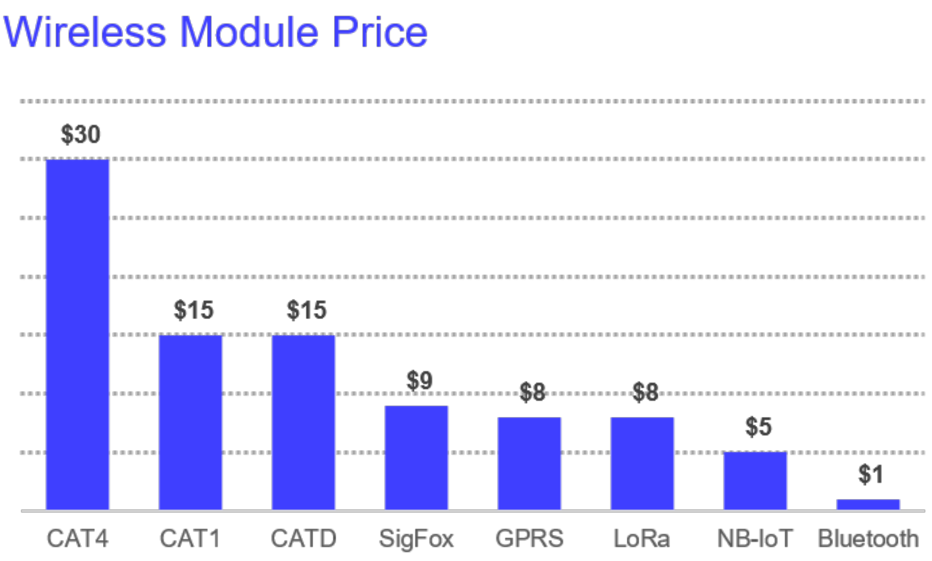

Figure 2.10: Wireless Module Price (Huawei, 2016)

The most common NB IoT applications are found within various public and private sectors. These include, but are not limited to, smart metering (utilities), alarms, asset tracking, and smart agriculture (Huawei, 2016). Among all of these applications are the common attributes of low maintenance costs, minimum device intervention, and large geographic coverage. Moreover, these applications are proven to be reliable in practice, as demonstrated by Huawei's China Unicorn marking meter program and water metering solution delivered with Vodafone in 2015 (Huawei, 2016). Overall, the low-cost, low-maintenance, and high-coverage characteristics of NB IoT make it incredibly appealing for corporations seeking to implement product-integrated technology. The downside to the technology, however, is its often large or non-functional physical form it takes as a commercial sensing product. The lack of innovation in NB IoT size reduction is a daunting hurdle for space-constrained applications. This trade-off is critical for public and private implementation initiatives to consider early in the design phase of IoT ventures.

2.3.2 Mesh Networking Technology

Most wireless network types are star networks. Star networks are composed of devices that are all uniquely connected to a single central device, which then connects its subsequent devices to the secondary cloud network. Wireless Mesh Networks (WMNs), on the other hand, are composed of devices that are all connected to themselves, then directly to the cloud network through one of the devices. WMNs are communication networks made up of radio nodes organized in a mesh topology instead of a star topology (Liu et al., 2017). Figure 2.11 depicts the differences between a star and mesh network.

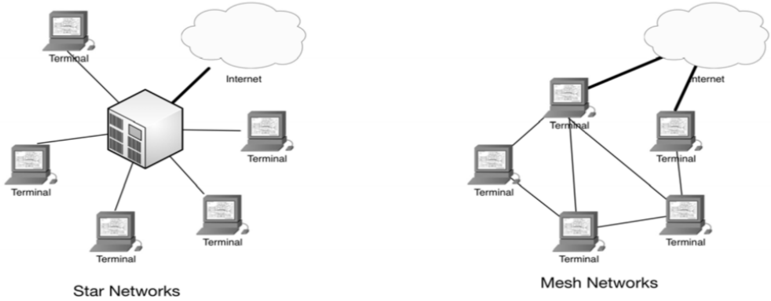

Figure 2.11: Mesh Versus Star Network (Liu et al., 2017)

Mesh network IoT configurations have a few distinct advantages. Primarily, expanding coverage of the network is fairly simple. In most cases, simply connecting a new router within the geographic range of existing network devices is sufficient to amplify coverage in a new area (Liu et al., 2017). Moreover, once installed and powered, devices connect to the existing network automatically. This type of flexibility minimizes the amount of technical expertise and disruption required to service or expand existing WMNs. This ease of accessibility minimizes the cost of establishing networks in hard-to-access or remote areas without reliable coverage, such as rural regions (Liu et al., 2017). Furthermore, WMN system energy costs are typically lower than other IoT network infrastructures. Because most devices are connected over shorter distances than they are with a star network design, they do not require a central node to continuously connect distant devices (Liu et al., 2017). This shorter connection span reduces the energy required to power central devices.

WMNs also prevent a few disadvantages. A substantial amount of hardware is required to create the WMN. Without an existing WMN in place, routers and connection points must be established in every area of potential use. Additionally, significant limitations exist with respect to the amount of data the end-node IoT devices can transfer while on a WMN (Liu et al., 2017). If the practical requirements of an IoT system require significant amounts of data transfer, a WMN may not be the best choice.

2.3.3 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a newly-popular method for tracking items throughout supply chains. RFID systems are composed of three components: a 1) tag 2) interrogator and 3) controller, as shown in Figure 2.12 (Hunt et al., 2007). A tag, also called a transponder, typically consists of a small chip-based device, antenna, and sometimes battery (Hunt et al., 2007). The tag attaches to the desired device to be tracked. The interrogator serves as the read/write device for the system - this is what identifies the tag and its characteristics. The interrogator communicates information to and from the tag via radio waves whenever the tag is within the read zone of the interrogator. Lastly, the controller is responsible for receiving and updating information from the interrogator(s). As the interrogator retrieves new information from the tag, it transmits information to the controller via a standard LAN or wireless network (Hunt et al., 2007). Thereafter, the controller, often in the form of a

PC or workstation, updates the desired database with data from the interrogator (Hunt et al., 2007). This three tier processed is outlined in Figure 2.12.

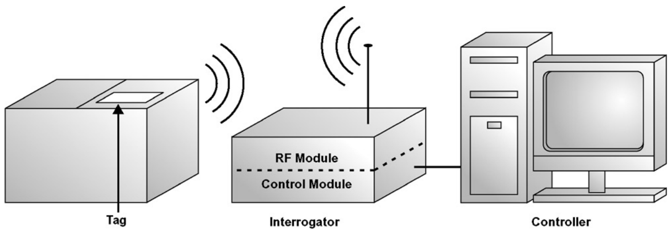

Figure 2.12: RFID System Device Configuration (Hunt et al., 2007)

These networks may have multiple tags and transponders established on the same system, creating significant flexibility for diverse applications. RFID technology applications fall into two categories: active and passive. Active RFID does not require the use of a stationary reading device and can transmit a signal across multiple miles. However, given the current cumbersome size, minimal battery life, and exorbitant cost of this technology, is it not being considered at length for this practical case. Passive RFID, on the other hand, is achievable in many ways. Simply put, passive RFID technology enables a sensor to communicate with an immobile reader. This reader receives information from the sensor and transmits the sensor's information up through an established wireless network. RFID technology networks can be separated into four distinct categories: low frequency (LF), high frequency (HF), ultra-high frequency (UHF), and microwave (Lewis, 2004). The frequency range of these various networks range from less than 135 KHz (LF) to 2.45 GHz (microwave), as outlined in Table 2.1 (Lewis, 2004). The primary considerations and trade-offs when considering RFID networks are 1) read range, 2) tag size, and 3) tag cost.

	LF	HF	UHF	Microwave
Frequency Range	< 135 KHz	13.56 MHz	860 - 930 MHz	2.45 GHz
Standard Specifications	ISO/IEC 18000-2	ISO/IEC 18000-3 AutoID HF class 1 ISO 15693 ISO 14443 (A/B)	ISO/IEC 18000-6 AutoID class 0, class 1	ISO/IEC 18000-4
Typical Read Range	< 0.5m	~ 1m	4-5m	~ 1m
General	- Larger antennas resulting in higher cost tags - Least susceptible to performance degredations from metals and liquids	- Less expensive than LF tags - Best suited for applications that do not require long range reading of high number of tags - This frequency has the widest application scope	- In volume, UHF tags have the potential to be cheaper than LF or HF due to recent advances in IC design - Good for reading multiple tags at long range - More affected than LF and HF by performance degradations from metals and liquids	- Similar characteristics to UHF but faster read rates - Drawback is microwaves are much more susceptible to performance degradations from metals and liquids
Tag power source	Mainly passive using inductive coupling (near field)	Mainly passive using inductive coupling (near field)	Active and passive tags using E-field back scatter in the far field	Active and passive tags using E-field back scatter in the far field
Typical applications	- Access Control - Animal tagging - Vehicle immobilizers	- Smart cards - Access Control - Payment - ID - Item level tagging - Baggage control - Biometrics - Libraries - Transport	- Supply Chain pallet and box tagging - Baggage handling - Electronic toll collection	- Electronic toll collection - Real time location of goods

Table 2.1: Passive RFID Frequency Characteristics (Lewis, 2004)

The read range of passive RFID tags ranges from less than 0.5m with LF technology to about 4-5m with UHF technology (Lewis, 2004). While vastly different on a small scale, these ranges are minimal compared to other IoT network technology scales capable of connecting over multiple miles. Tag size, while also varying, is relatively small. Passive RFID tags can be as small as the hotel key cards that fit in a wallet, or the security tags that are attached to expensive clothing items at retail stores. Additionally, tag costs are generally less than one U.S. dollar, making them financially accessible for most applications.

As previously mentioned, passive RFID technology requires the mobile tag device to come into close proximity with stationary readers (Lewis, 2004). The determination of required readers and associated support networks can be cumbersome. Additionally, the business and financial relationships required to establish these reader networks across different organizations can be daunting, if not impossible. While passive RFID systems are reliable and have a low financial barrier to entry, they are typically most successful when implemented within a single organization.

2.3.4 Bluetooth Network Design

Bluetooth technology allows devices to connect across short distances. Primarily, Bluetooth technology was created for short-term communications between wireless devices such as headphones, keyboards, and portable cell phones as a means for wireless communication between equipment and devices (Harte, 2004). Although it originally formed as a means for wireless audio communication, Bluetooth technology has rapidly expanded to various applications including tracking, advertising, and external beacons for Bluetooth-enabled smartphones. Examples of these devices are shown in Figure 2.13.

Figure 2.13: Bluetooth Sample Devices (Harte, 2004)

The characteristics of Bluetooth include an unlicensed frequency band that ranges from 2.4 GHz to 2.483 GHz (Harte, 2004). This frequency band was chosen because it is available for use in most countries throughout the world (Harte, 2004). Connectivity options for Bluetooth include Classic Bluetooth and Bluetooth Smart (or Bluetooth Low Energy, BLE) for point-to-point, mesh, or other networks (Silicon Labs, 2019). While Bluetooth Classic is able to transmit at a higher communication range, Bluetooth Smart uses significantly less power and cost overall (Silicon Labs, 2019).

Overall, Bluetooth has significant advantages when creating an IoT network. For example, it has a low barrier to entry from a development perspective. Smartphone companies such as Apple and Google have provided mature tools for developing the applications needed to access external Bluetooth devices (Silicon Labs, 2019). Therefore, IoT device developers can easily design devices with instant compatibility with major smartphone manufacturers without having to invest in lengthy and costly integration configuration. This ease of development has triggered the explosion of Bluetooth applications in various commercial applications. Additionally, Bluetooth devices are both physically small and consume low levels of power. Oftentimes, Bluetooth tags can be as small as a quarter or house key.

Furthermore, the average cost of Bluetooth device tags is the lowest among all IoT devices. The average cost of a Bluetooth device is only $1, as shown in Figure 2.9 (Huawei, 2016). This low financial barrier provides significant flexibility for application in ambiguous environments. However, Bluetooth technology also has its disadvantages, primarily range. Bluetooth tags typically cannot be detected more than a few hundred feet away from the active devices that read them (e.g. cell phones). Moreover, these tags are passive and require pinging from the connection device in order to transmit data. As the number of Bluetooth-capable devices grows, signal congestion and interference may become a concern. Because the utilization of Bluetooth bandwidth is not regulated nor licensed, signal congestion at similar frequencies can slow or prohibit connections during peak times (Harte, 2004).

2.3.5 Sigfox Network Design

Founded in 2010, Sigfox is a proprietary, privatized network solution that companies may leverage for their IoT needs (Sigfox, 2020). While most IoT network platforms are largely open-source with the opportunity for companies to build solutions on top of existing infrastructures, Sigfox is not. Mekki observes, "Sigfox deploys its proprietary base stations equipped with cognitive software-defined radios and connect them to the back end servers using an IP-based network," (p. 2). Moreover, Sigfox sells its solutions in various form factors: transceivers, modules, development kits, and others. Sigfox's privatized network provides companies with a reliable service model to maintain network infrastructure and connectivity.

Sigfox IoT tracking devices range in size. Based on the retail inventory listed on its website, Sigfox appears to have dozens of device options with an average device size similar to a luggage tag (Sigfox, 2020). Furthermore, the average device price in 2020 was around $9 in a traditional single-unit retail environment. Given its private network design, a critical factor for companies considering Sigfox solutions is its network coverage. Figures 2.14 and 2.15 depict Sigfox's network coverage in the United States and Europe, respectively, as of March 2020. Light blue indicates regions where coverage already exists, while the purple indicates regions where coverage is currently being rolled out.

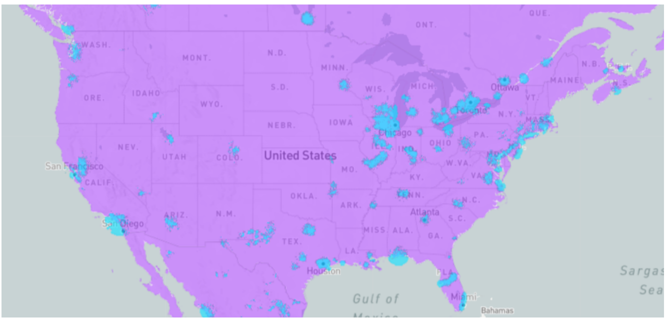

Figure 2.14: Sigfox Coverage Map: United States (Sigfox, 2020)

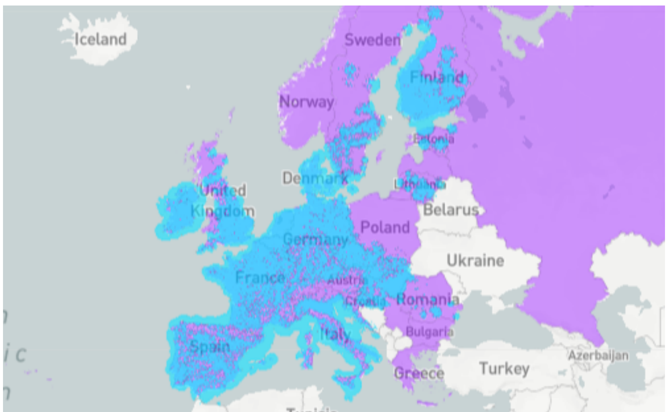

Figure 2.15: Sigfox Coverage Map: Europe (Sigfox, 2020)

As indicated in the maps above, Sigfox does not currently have nationwide coverage in the United states. While it does have established coverage zones in major U.S. cities such as Chicago, San Francisco, and New York City, the lack of coverage across the country is sufficient to prevent a corporation of the sponsor's scale from employing its network services. While it may be growing its coverage areas, Sigfox's current U.S. coverage of less than 10% is simply too little to provide a practical result for the sponsor's large-scale tracking needs. This is a potential solution for the sponsor to consider in future years if the Sigfox coverage area expands in conjunction with lowered tracking device size and pricing. However, the existing high level of coverage in Europe may indicate a feasible solution for the sponsor's parent company's business solutions at this time.

2.3.6 Technology Comparison

Five major considerations need to be considered when selecting the most viable path forward for the sponsor: battery life, cost, device size, communication range, and beacon requirements. Table 2.2 displays an aggregated view of the general characteristics for each IoT network's critical variables.

Platform	Battery Life	Size Comparison	Avg. Cost	Read Range	Local Beacon
Narrow Band	3 - 10 yrs	Calculator	$5	< 38 km	No
RFID	3 - 5 yrs	Coaster	$0.10 - $0.15	0.0005 - .1 km	Yes
SigFox	1 - 10 yrs	Luggage Tag	$9	3 - 50 km	No
Bluetooth	0.5 - 3 yrs	Coin	$1	< .152 km	Yes/No

Table 2.2: IoT Technology Comparison

The most feasible technology option for the sponsor's application is Bluetooth technology. Bluetooth technology provides the lowest cost, smallest size, and most autonomous solution of all available technologies at this time of writing. While Bluetooth devices typically do not have the longest battery life, the existing battery range is sufficient to meet the sponsor's inventory shelf life of one to two years. Additionally, Bluetooth's detection range is near the median of available platforms - less than 10% of Narrow Band and SigFox alternatives. However, given the accessibility and close range of its mesh-like, public cellular beacons, this is not a critical weakness. Given the cost, size, and autonomy of Bluetooth IoT networks, it is clearly the best path forward for the sponsor's pharmaceutical application.

2.4 SIPOC Approach

The SIPOC (short for Supplies, Inputs, Process, Outputs, and Customers) approach generates value by producing a quick, simple, and high-level overview of a defined process and its components' interdependencies (Rasmusson, 2006). The model details the suppliers, inputs, processes, outputs, and controls of a defined operation or process. SIPOC begins with a top-down view of a system while delivering micro-examinations of the tasks that support process or operation of interest. A SIPOC table or diagram is used to categorize the different areas that interact with each other throughout the process being evaluated. The SIPOC tool can either be leveraged in a map or table format, as shown in Figures 2.16 and 2.17, respectively. Map formats, as shown in Figure 2.17, can be helpful to visualize a process that is initially complex or ambiguous for stakeholders to understand.

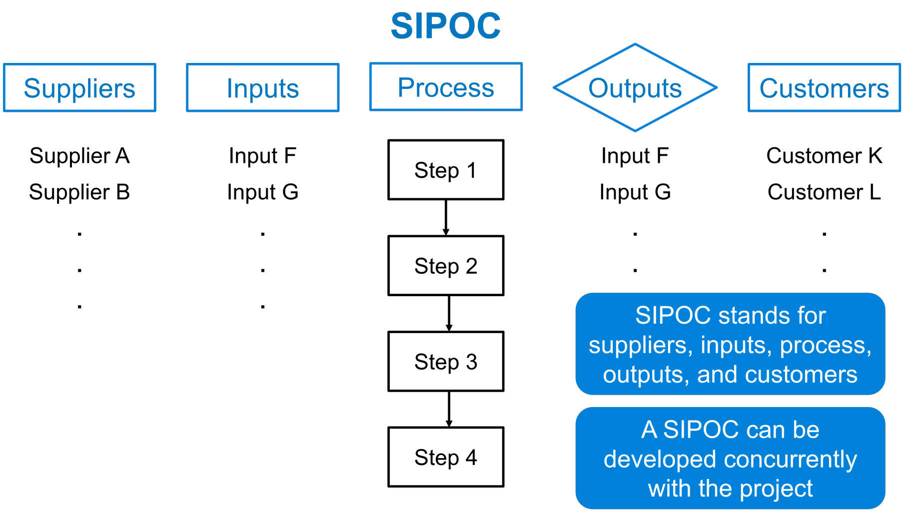

Figure 2.16: SIPOC Process Map (Rasmusson, 2006)

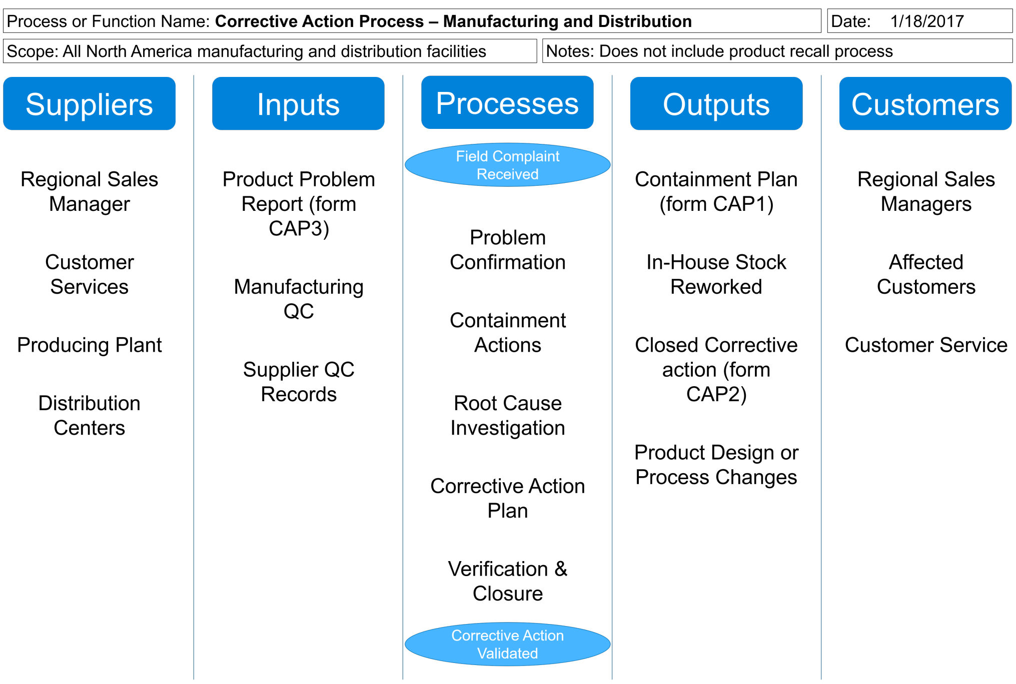

Figure 2.17: SIPOC Process Example: Table Format (SIPOC Diagrams, 2020)

Map formats can be helpful to visualize a process that is initially complex or ambiguous for stakeholders to understand. Rather than using a SIPOC map, the team leveraged a table that simply lists each component of the SIPOC methodology in a more functional format. For the purposes of this study, the SIPOC tool was primarily used to outline cross-functional components of the sponsor's supply chain. In this case, the tool's value was to ensure that no supply chain stakeholders were excluded from any part of the supply chain impact study. The tool's structure of identifying high-level processes and detailing each processes' supplier, input, output, and customer ensured the team encapsulated all of the sponsor's supply chain stakeholders and partners that may be affected by an IoT implementation.

3 METHODOLOGY

3.1 BACKGROUND

The applications of IoT technology have blossomed as devices and infrastructures become more practical and inexpensive. Given the size, cost, and regulatory requirements of manufacturing and shipping pharmaceutical products, use of IoT as an end-to-end inventory tracking solution is in its infancy as a solution for pharmaceutical manufacturers. Therefore, the following methodology and solutions discussed in this study are exploratory and naïve. To identify practical solutions, the team must first understand what level of tracking is possible. The methodology outlined in this chapter depicts various possible solutions, explored through projections and real-world experiments, and projected corporate benefits of each solution.

3.2 REAL-WORLD CAMBRIDGE EXPERIMENT

3.2.1 PRODUCT INTRODUCTION

As outlined in the Literature Review, the most feasible IoT network platform for the sponsor company is Bluetooth technology. Numerous corporations have created small IoT devices used to track individuals' personal items, such as keys and wallets, through Bluetooth signals that connect to users' cell phones. This connection of physical trackers to cell phones essentially creates a Bluetooth mesh network. A potential IoT inventory tracking solution for the sponsor company is to leverage one of these device platforms to embed Bluetooth trackers within the sponsor company's product packaging. After delivery to the store, the Bluetooth trackers connect to an accessible Bluetooth wireless network to transmit location and time data back to the sponsor company, creating a real-time inventory snapshot of the retailers' sponsor company inventory levels.

One example of an existing Bluetooth tracker provider is Company X, a manufacturer of small key-chain-like Bluetooth tags. Company X manufacturers and sells small key-chain-like trackers to consumers to help them track everyday items likely to be misplaced. Once a tag is purchased, the customer downloads the Company X application to their mobile device. The application, through the phone's Bluetooth and cellular network, tracks and manages the owner's Company X tag location and historical data. Company X's Bluetooth tags connect to any Company X customer's phone within the device's read range (between 150 and 400 ft., depending on the model). Customers' mobile phones, through the app, then autonomously transfer tracker data (location, time, etc.) through their respective cellular networks to Company X's database. Figure 3.1 depicts the connection flow between a Bluetooth tracker, implanted within the sponsor company's product packaging, to consumers' cell phones, to Company X's database through cellular signals.

Figure 3.1: Company X Bluetooth Connection Structure

If a customer loses the designated item or tag, he/she can use their Company X application to leverage the Company X community of users whose mobile devices have come within read range of their device to locate the lost tag. The device's location coordinates, now "found" by other users' cell phones and transmitted to Company X's database, is then shared from Company X and electronically transferred to the device's owner so it can be retrieved.

3.2.2 Approach Overview

In order to project the effectiveness of this proposal on a national, full-scale implementation level, the team needed to project the potential frequency of natural Company X user data collection through the presence of trackers at the sponsor company retailers. In other words, answering the question: "How many times does a Company X customer, with the Company X app, come within Bluetooth range of the sponsor company products in their customers' inventory storage areas (retail pharmacies, hospitals, clinics, etc.)?" Answering this question on a national level is challenging given the degree of diversity in American regions: cities versus rural areas, West coast versus East coast, age demographics, pharmacy accessibility, and more. Further, the team crafted the solution in two phases:

1. Local Company X deployment experiment as a technology proof-of-concept
2. Data analysis for national Company X deployment model and implications

Phase one involved attempting to project Company X ping frequency for a specific, known geographic area. After projecting ping frequency in this area, the team deployed physical Company X trackers at target pharmaceutical locations around the area and collected data to test the ping frequency hypothesis. After collecting ping frequency data from the deployed trackers, the team analyzed the data and adjusted their initial assumptions and calculations to create a national forecasting model for the sponsor company inventory visibility through future tracker deployment. Ultimately, this two-tier approach provides a baseline for how practical the Company X (or similar Bluetooth infrastructure) solution may be in the retail pharmacy industry.

Notably, this experimental approach does not include assessing the feasibility of such technology in the hospital or clinical healthcare environments. These customer segments were intentionally excluded for two primary reasons. First, these customers represent a minority of the sponsor company's sales relative to the revenue volume that flows through retail pharmacies. Second, hospital and clinical environments were excluded due to their high barrier to entry. The open, consumer-focused shopping nature of major pharmaceutical retailers facilitates easy access and monitoring. Hospitals and clinics, on the other hand, are more controlled due to the information protection of their patients and customers. Moving forward, these markets may be targeted for Bluetooth trials after establishing appropriate partnerships with the responsible company employees or executives.

3.2.3 Ping Frequency Hypothesis

The word "ping" is commonly used to refer to a communication instance between an IoT tracker and detection device. When an IoT tracker, such as a Bluetooth tag, "pings" off of a customer's mobile device, it represents the specific connection and communication instance between the mobile device and Company X tag, which is then transmitted back to Company X's database. From this point onward, the word "ping" will be used to describe a unique connection between an IoT tag and detection device, such as a Company X tag and user's mobile phone.

The regional scope of this analysis was restricted to the city limits of Cambridge, MA, due to its close proximity to the MIT team. Moreover, the Cambridge, MA region houses retail locations representing a wide variety of demographics, including both populous urban environments and residential/suburban shopping environments. This diversity assisted the experimenters in extrapolating results from the Cambridge, MA region to a national level when analyzing and projecting the results. As mentioned previously, the business and application scope of this analysis was for retail pharmacies only. It does not, however, include hospitals or health clinics. Lastly, the ping frequency projection only includes data from each store's direct patrons. It does not include potential pings from nearby pedestrians, nor does it include potential pings from nearby vehicles or delivery services.

To begin, the team estimated the number of pharmacies in Cambridge, MA. Based on simple Google Maps searches for primary name-brand pharmacy retailers, the team identified a total of 20 pharmaceutical locations in Cambridge, MA. It is critical to acknowledge that by default, a Google Maps search will only return up to 20 results. Understanding this search constraint, the team ran multiple iterations of the search across different subsections of Cambridge's city limits to ensure that no locations were omitted as a result of the search constraint. Table 3.1 outlines the total number of pharmacies in Cambridge, MA, segmented into three major retailer categories: Chain 1, Chain 2, and Other.

Retailer	Number of Locations
Chain 1	9
Chain 2	6
Other	5
Total	20

Table 3.1: Cambridge Experiment Retail Locations

Next, the team deduced the average number of pharmaceutical visits by Americans in a given period of time. Based on a consumer analysis article from CVS, 69% of Americans visit a pharmacy at least once per month (CVS, 2019). Without knowing a specific mean or standard deviation, the team leveraged a triangular distribution to estimate the average visits per American per month. Given that 69% visit greater-than or equal-to one time per month, the mode of the distribution must be at least one. For this experiment, the team assumed that the mode is equal to one to preserve a conservative estimate given the lack of upper-bound data. Additionally, the team conservatively assumed that the maximum number of times an individual visits a pharmacy is four times per month, which is about once per week. This estimate is purely based on experience and intuition. Naturally, the minimum number of visits per month is 0. Therefore, the triangular distribution variables (minimum, mode, and maximum) are 0, 1, and 4, respectively, and are defined in Table 3.2.

Variable Name	Definition
a	Minimum visits per month per customer
b	Maximum visits per month per customer
c	Mode or most-frequent visits per month per customer

Table 3.2: Cambridge Experiment Variable Definitions

Based on the variable definitions presented in Table 3.2, we can calculate the expected number of visits per month in Equation (3.1) as

$$E[X] = \frac{a+b+c}{3} \tag{3.1}$$

Therefore, with $a = 0$, $b = 4$, and $c = 4$, we obtain an expected number of 1.67 visits per month. This monthly forecast can be extrapolated to the expected number of visits per day by dividing over 28 (assuming 28 days per month). This yields a daily projection of 0.06 visits per pharmacy per day per American. While it is obviously impossible for a person to have a non-integer number of visits to a location, this value is still useful for aggregate estimate projections.

Lastly, the Company X app is designed to display its local user community population in each user's respective region. Therefore, the team was able to gather data regarding the total app user population in Cambridge, MA in November 2019. In order for this entire population to be considered as potential mesh network nodes, this data analysis includes a few key assumptions: 1) all Company X users have Bluetooth enabled and are sharing their location with the application 2) the Company X user figure only includes users who still have the app and not users who have potentially deleted or deactivated the app and 3) all users reside within the Cambridge, MA area (an assumption later debunked in Chapter 4). Using the data compiled above, the team projected the number of user pings per pharmacy per day in Cambridge, MA. Equation (3.2) depicts this result, where N is the number of Company X users, v is the average customer visits per day, s is the number of pharmacies in Cambridge, and p is the number of pings per day.

$$\frac{Nv}{s} = \frac{p}{s} \tag{3.2}$$

This analysis yielded a projected figure of 43.9 pings per day per pharmacy in Cambridge, MA. The list below outlines critical assumptions made when created the projected pings per day figure. These assumptions were reviewed at the end of the Cambridge Company X Experiment for relevance based on the results of the study.

- Company X users follow the same pharmaceutical habits and preferences as the average American
- The time frame of the Cambridge Company X experiment reflects similar demand patterns of the time frame used for the CVS consumer analytics report
- All stores have a physical footprint smaller than a 200 ft. radius; all customers will be close enough to the inventory to ping the Bluetooth trackers
- No stores were missing from the store data identified
- No pedestrian data was included for pedestrians near stores who could ping trackers
- No vehicle data was included for drivers near stores who could ping trackers
- All days were treated equally; the analysis does no stratify customer visit density based on day-of-the-week or holidays
- All Company X users had the location service and Bluetooth service activated on their phone
- All Company X users still had the app and no users have potentially deleted or deactivated the app
- All Company X users in the "Cambridge" area resided within Cambridge, MA

3.2.4 Pilot Data Collection - Cambridge, MA

At the time of this writing, Company X manufactures and sells numerous products, ranging in characteristics such as size, battery life, and cost. Of these models, the "Long" tag has the median detection range (200 feet), median battery life (one year), and median size. Based on these characteristics, the team acquired 20 Long tags for this experiment. Additionally, the MIT and the sponsor company teams established a working partnership with Company X's customer support team. This partnership included establishment of an API connection into Company X's database for the 20 specific Long tags the team acquired, allowing the research team to obtain all tracking details and history associated with the acquired tags after activation. Based on sales volume and retailer inventory storage environments, the detection and battery range of the Company X Long model is sufficient to simulate an actual use case.

Each tag was designated with a unique identifying number between one and 20, then assigned to a specific storefront location. Upon deployment, each tracker was physically hidden somewhere inside the retailer within 30 feet of the pharmacy counter. This proximity to the pharmacy was intended to simulate the sponsor company's product inventory typically stored behind the pharmacy counter. In this case, the deployed tracker mirrors a potential tracker within a sponsor company case, box, or vial storage container. Considerations for placement included visibility and communication barriers. For example, while placing a tag within a metal display rack may keep it hidden, the metal structure may act as a Faraday cage and prevent transmission of a signal between the tag and user phones. Often, the tags were placed within cardboard or paper end cap displays or greeting card slots where they would not be discovered and could still transmit a signal. This combination of signal accessibility and low visibility ensured a longer data collection window without discovery and removal of the tags.

Between November 21 and 22, 2019, the MIT team cascaded and deployed all 20 of the Company X Long tags to the 20 targeted retail pharmacy locations within Cambridge, MA. Upon deployment, each tag was tested through the Company X mobile application to ensure it was sending a clear signal from its resting point. Unfortunately, one of the tags did not transmit a signal due to either a battery or technology malfunction. While potential manufacturing defects are important to consider when calculating large-scale implementation risks, this specific tag was over a few months into its life cycle and believed to be a special-cause outlier. However, this occurrence highlights the importance of the sponsor company evaluating the long-term failure rate of its eventual device provider. Due to this malfunction, only 19 of the targeted pharmacies produced data over the course of the experiment.

3.2.5 Company X Cambridge Experiment: Data Collection Considerations

With the trackers placed at the selected pharmacies, the team captured consumer ping data between November 22, 2019 and March 1, 2020 - a total of 100 days. The sample includes multiple major United States holidays (Thanksgiving, Christmas, and New Year's Day) and an unseasonably warm winter for the greater Boston, MA area. Given the limited opportunity to collect data over the course of multiple years, seasonality effects such as these will not be quantified in the data analysis portion. Rather, their influence may or may not be present in the data, which poses forecasting risk for year-round, nationwide implementation moving forward. However, the factors potentially contributing to increased pharmaceutical sales over this seasonal period should be somewhat offset by the retailers' wide range of products and offerings (food, utilities, photo services, cosmetics, etc.). This diverse product portfolio should drive some level of consistent foot traffic regardless of peaks or troughs in pharmaceutical demand.

External factors that will be taken into consideration for the density distribution analysis include proximity to public transportation, proximity to universities, store brand, and weekday. Other factors that will also be analyzed are unique users (potential for a pharmacist to be a Company X user and thus give false-positive readings), time of day, day of week, and any realizable effects of holidays. The broad assumption that all Company X users actively share location, maintain app storage, and use Bluetooth functionality may also be studied through a density experiment in the Cambridge, MA geography.

3.3 Supply Chain Implementation

Implementing the proposed technology solution requires a deep understanding of the underlying supply chain network, stakeholders, and external relationships to ensure a successful outcome. Section 3.3 outlines the team's methodology for approaching the implementation planning aspect of the project from a business perspective and the individual supply chain operations. While interviews were conducted to gain a deeper understanding of the sponsor company's specific operations, the insights obtained will also be generalized to a broader supply chain level. This high-level analysis will allow the sponsor company to implement a similar approach for future IoT implementations, regardless of device type or network infrastructure.

3.3.1 Business Scope

The sponsor company is a multi-billion dollar organization. Its product portfolio consists of dozens of prescription-based and over-the-counter solutions. Therefore, it is impractical to envision implementing a novel IoT implementation across the sponsor company's entire product platform. Rather, a small subset of product(s) needed to be selected to effectively monitor the solution for challenges and improvement opportunities before implementation on a large scale. The MIT team leveraged the sponsor company's innovation group to partner with additional sponsor company divisions and identify a product or brand team suitable for piloting the IoT technology. Ultimately, the sponsor company's preference was to limit the product scope to a specific medication, referred to henceforth as "Product A".

Product A is manufactured, packaged, and shipped in small rectangular boxes. It is sold in most pharmacy locations, including major retailers, hospitals, and clinics. In addition to previously-reviewed cost mitigation benefits (such as supply chain data acquisition savings), the sponsor company may leverage Product A inventory visibility to better forecast and respond-to localized demand spikes. Immediate inventory visibility at the customer level would allow the Product A team to accelerate its timeline of meeting demand in highly concentrated regions, capturing revenue that is currently missed without IoT tracking. Between the sponsor company's large appetite for innovation and Product A's current size and growth opportunities, Product A is the perfect pilot development product.

3.3.2 SIPOC Approach

This capstone leveraged the SIPOC methodology, as outlined in Chapter 2, to define the supply chain impact and integration strategy for an IoT solution within the sponsor company's supply chain. Through research, supply chain case studies, and interviews with sponsor company subject matter experts, the team identified key stakeholders and barriers to the sponsor company's IoT implementation through the SIPOC framework and methodology.

First, the team identified the core supply chain functions of the sponsor company's target product. Through an understanding of the sponsor company's supply chain structure and previous industry knowledge, the team created a high-level list of each supply chain process: procurement, packaging, manufacturing, warehousing, inventory, transportation, distribution, customer relations, and reverse logistics. Additionally, after further review, the team added ancillary support groups that are pivotal to the project's success, albeit not traditional supply chain fields: legal and environmental, health, and safety (EHS). After creating this comprehensive list of Product A supply chain processes, the team calibrated each process with its sponsor company point of contact and verified that all proposed processes were relevant and nothing critical was omitted.

Based on the list of key processes, the team scheduled interviews with the sponsor company's designated SME for each process. The goal of these interviews was to get the team's functional questions answered and, at a higher level, discuss the IoT proposal with each SME to understand their concerns. Rather than taking a strictly academic approach to the problem, the team felt that including the sponsor company's internal experts, who would ultimately own the IoT implementation for their respective functions, was the best path to understand the true challenges facing the company's implementation. In each interview, the team peppered the sponsor company's SME with questions pertaining to the cost and complexity of adding a Company X tag to Product A packaging. For example, questions involving the transportation function focused on shipment methods, transportation modes, freight capacity, loading and unloading methods, shipping regulations, etc. Given the answers to these questions, as well as additional insights through SME conversations, the team was able to identify the critical suppliers, inputs, outputs, and customers associated with each process of the sponsor company's Product A supply chain. Table 3.3 details each SIPOC interview conducted, including the target process, sponsor company SME, and date the interview was conducted.

Process	Job Title	Date Conducted
Product A Team	Channel Analytics Manager	2/25/20
Product A Team	Channel Inventory Manager	2/25/20
Logistics	SCM Senior Supervisor	3/2/20
Distribution/Customer Relations	Senior Supervisor	3/2/20
Manufacturing	Senior Packaging Engineer	3/13/20

Table 3.3: SIPOC SME Interview List

After conducting these interviews, the team completed the SIPOC table, identifying the key suppliers, inputs, outputs, and customers associated with each supply chain process. This analysis, with detailed considerations for supply chain risk and implementation, is detailed further in Chapter 4.

4 Results and Discussion

4.1 Company X Cambridge Experiment

Between November 22, 2019 and March 1, 2020, the research team collected 9,280 data points over 100 days. There was no scientific reason for concluding data collection on March 1. The team simply ceased data collection from its API (Application Programming Interface) into Company X's database on March 1 to draw a clear end to the data collection process, knowing that the 9,280 data points were sufficient to draw statistically significant conclusions.

4.1.1 Initial Ping Data Results

To gain a high-level overview of the tracker pharmacy locations and their ping frequencies relative to one-another, the team began by mapping the Company X tracking locations. This geographic density view is shown in Figure 4.1 and is oriented in the traditional N-E-S-W format.

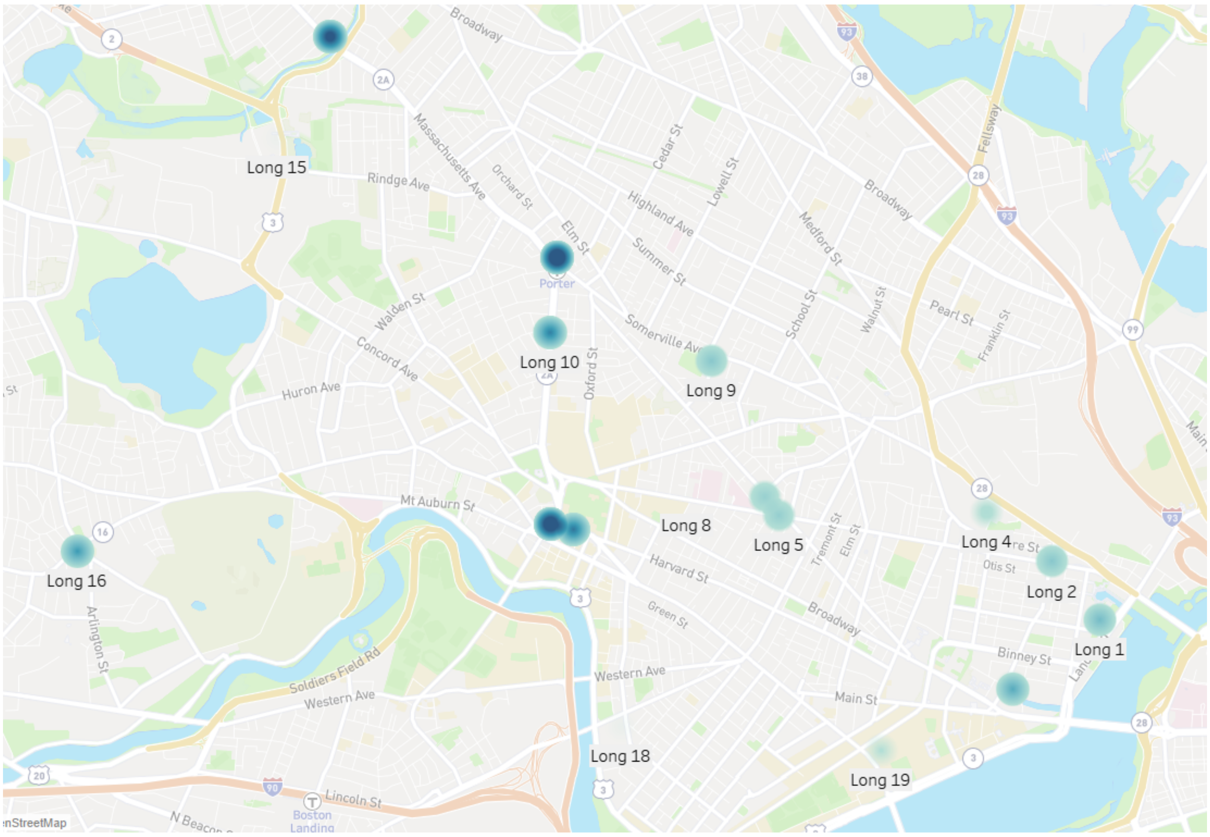

Figure 4.1: Ping Density Map - Cambridge Experiment

The tracker tag's geographic coordinates, returned by the Company X API database, were mapped through Tableau's geographic plotting feature. Leveraging a density map, where the density of ping data points is indicated by the intensity of blue, a simple visual analysis is created to interpret tracking locations and ping frequency. Without conducting thorough analysis, it appears that locations near the Northwest quadrant of Cambridge have higher ping frequencies than those in the Southeast quadrant. At first glance, driving forces behind this result may be the presence of Harvard University campus in the Northwest corner and the de-aggregation of shopper volume in the Southeast corner due to a higher concentration of retail locations. These, as well as other factors such as shopper demographics, retail brand, etc. may be considered moving forward to draw more causal relationships between deployment areas and ping frequency forecasts.

Before conducting rigorous statistical analysis regarding the ping frequency of pharmaceutical trackers, the team reviewed the data at a high level using basic summary statistics and various groupings. To begin, the data was grouped by retail store location. This level of stratification provided insights into the different characteristics of customers that may drive high or low probabilities of Company X consumer access: location, retail brand, operating hours, product variety, etc. Figure 4.2 displays a bar chart of the total number of pings per pharmacy location. Dark blue tones are leveraged as an additional visual tool to indicate higher ping frequencies, while light blue tones indicate low ping frequencies.

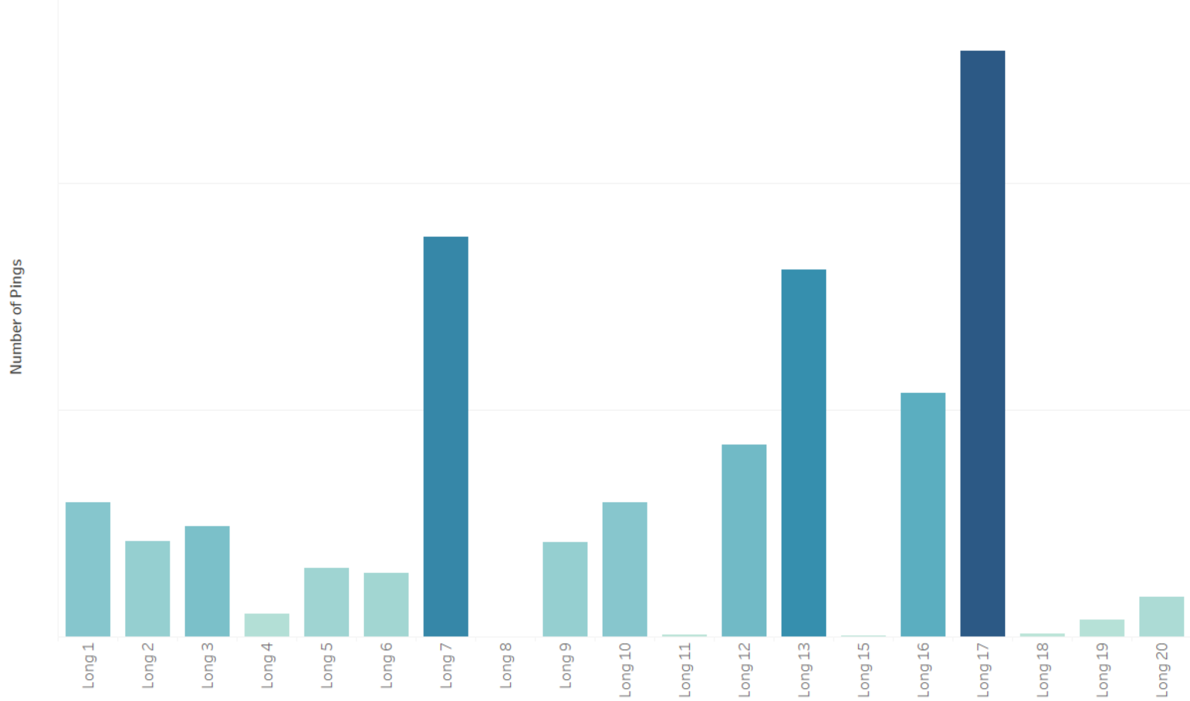

Figure 4.2: Ping Distribution - Cambridge Experiment

As indicated in the graph, the stores can be split into three general groups regarding ping levels: high, medium, and low. This is not done using a formal grouping method (such as k-means clustering) but rather by simple visual observation. The "high" group includes three locations: Long 7, Long 13, and Long 17. These stores account for over half of all store ping data combined, following a Pareto-like pattern. The most obvious shared characteristic among these locations is their retail brand: Chain 1. Stores 7, 13, and 17 are all Chain 1 retail locations with a high diversity of products. Geographically, stores 7 and 17 are both in high foot-traffic areas with minimal surrounding retail competition. They are likely in real-estate properties with high prices per square foot due to the pedestrian exposure, such as Harvard Square in a bustling intersection of Cambridge. Tracker 13 is in a more suburban location with minimal foot traffic. This appears to be an outlier driven by external factors.

The medium frequency group appears to include six locations: Long 1, Long 2, Long 5, Long 9, Long 12, and Long 16. Unlike the high frequency group, the medium group does not share any obvious commonalities. Regarding retail brand, these stores are a mixture of national chains such as Chain 1 and 2, as well as smaller regional businesses. They also do not share any significant geographical commonalities, other than the presumed general Cambridge area.

The small frequency group includes nine different pharmacies: Long 3, Long 4, Long 6, Long 8, Long 11, Long 14, Long 18, Long 19, and Long 20. As previously mentioned, the Company X tag used for Long 14 is believed to be defective after in-app testing, so this result is likely a false negative and not included in further analysis. Similar to the medium frequency group, the small frequency group does not share any immediately-obvious commonalities. Retail brand, geographic location, and product diversity all vary across this group. A more detailed characteristic and distribution analysis will be covered in Subsection 4.1.2.

4.1.2 Ping Data Statistical Fitting

To understand the characteristics of the Cambridge experiment data set, it must first be correlated to a distribution type. In order to create a histogram of the data for distribution fitting, the ping data must be characterized. In this case, the data was grouped into a measure called "Pings per Day per Store". With this grouping, the data was separated into each store location, then further grouped into pings per day by summing the total number of pings at each store in each day. Therefore, each data point is a number of pings per day per store. With the raw data grouped into calculated data points, it was separated into buckets based on various ranges of pings per day per store. Based on the range of data points in this experiment, the bin range was set to two, meaning that each bin represents a range of two pings per day per store. Figure 4.3 depicts the histogram of pings per day per store, grouped by bin widths of two.

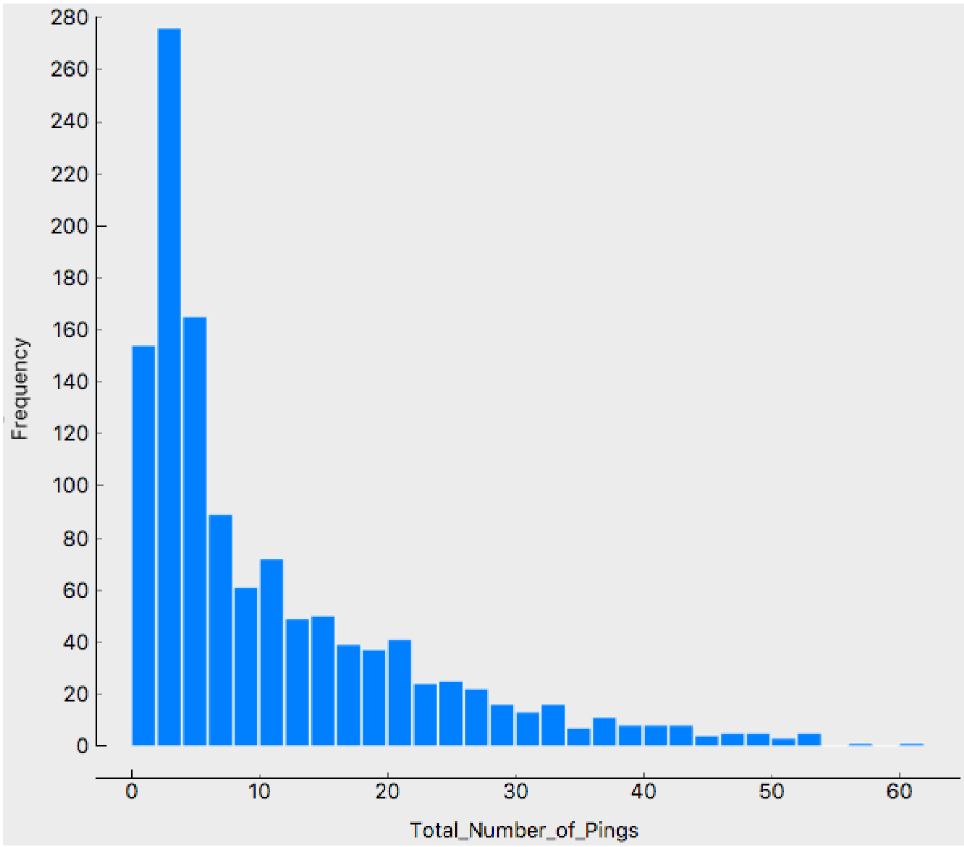

Figure 4.3: Daily Ping Distribution - Cambridge Experiment

Clearly, the lack of symmetry and bell-shaped curve proves that the data does not follow a normal distribution. The distribution has a clear left skew with a long tail to the right. This is traditionally representative of either a Poisson or exponential distribution. While the values are low, positive integers, the extreme skewedness toward zero does not lend this distribution toward being Poisson. Rather, it is likely an exponential distribution, based on visual observation. Creating a best-fit line of the Cambridge, MA pilot data provides a platform to correlate various attributes of the Cambridge area (number of Company X users, population density, etc.) to its distribution of pings. Moving forward, this type of factorization can be used in other cities to correlate their known unique variables to a forecasted ping frequency distribution. In order to fit the data to an exponential distribution, its values must be transformed from a linear dataset to an exponential dataset. This was executed using a log-level regression model. Furthermore, this type of model can be used to predict the distribution or likelihood of pings in various geographic regions moving forward. The standard log-level regression equation is shown in Equation (4.1).

$$ln(y) = \beta x + \delta \tag{4.1}$$

Equation (4.2) depicts the best-fit line correlating the number of pings to their likelihood for the Cambridge, MA experiment.

$$ln(y) = -0.405x - 1.38 \tag{4.2}$$

This exponential fit matches the theoretical equation with values β = -0.405 and δ = -1.38. The summary statistics produced by the regression are shown in Table 4.1.

Statistic	Value
R^2	0.908
P-value	0.003
Significance	0.003

Table 4.1: Regression Summary Statistics

Equation (4.2) inputs a given number of pings per day at a store and returns the probability of getting that many pings per day per store. For example, there is about a 16.8% chance of stores having exactly 1 ping per day. The remaining distribution is shown in Table 4.2.

Pings/Day/Store	Likelihood
0	25.23%
1	16.83%
2	11.23%
3	7.49%
4	5.00%
5	3.33%
>6	30.89%

Table 4.2: Exponential Likelihood of Pings/Day/Store

Ultimately, the purpose of the experiment was to determine the feasibility of the community-based Bluetooth infrastructure. As the customer of this implementation, the sponsor company must determine how to define a "feasible" or worthwhile level of ping frequency. The internal sponsor company team determined that a consistent return of at least one ping per day per retail location is "feasible" for this application. Simply stated, if the sponsor company is able to get at least one snapshot of Product A inventory per day for a retail location, the data is useful for its business needs. Therefore, using the Cambridge pilot data collected, the team was able to create loose projections regarding the likelihood of retailers achieving this metric.

Rather than summing the discrete probabilities of stores having greater-than or equal-to one ping per day, the team simply evaluated the likelihood of stores having zero per day and subtracted this from one. Given that $P(0) = 0.2523$, $P(\geq 1) = 0.7477$. Therefore, about 75% of retailers will have at least one ping per day. This metric provides a simple gauge of effectiveness for the sponsor company's implementation moving forward. However, this general metric does not include characteristic differences between implementation cities and Cambridge that may lead to discrepancies. These considerations are outlined in Subsection 4.1.3.

4.1.3 National Data Outlook

To create a practical vision for full-scale Company X implementation, the team needed to extrapolate the Cambridge pilot results across the United States. Given the lack of Company X user information and Product A customer demand, the following extrapolation focuses on creating ping frequency insights for pharmaceutical retailers in major cities across the United States. To create these projections, the team obtained Company X user populations in other cities. Additionally, the team created a means to correlate the Cambridge Company X user population and results with other cities' projected results based on their respective Company X user populations.

First, the team identified a way to gather Company X user data in different cities. This is the information that the Company X app provides users in whatever region their cellular device is located. The team leveraged their personal and professional networks in various cities across the country to obtain this information. Each participant downloaded, or used, the Company X application and navigated to the screen shown above. After observing the number of users in his or her respective area, each respondent sent his or her location and population report back to the MIT team. Data was gathered in late February 2020 and is representative of Company X's customer population in each area at that time. This collection of crowd-sourced data gathering for each available city is summed in the Table 4.3.

City	Census Population	User Density Range
Atlanta, GA	420,003	1.5 - 2.0%
Boston, MA	617,594	1.5 - 2.0%
Columbus, OH	787,003	0.5 - 1.0%
Denver, CO	600,158	0.5 - 1.0%
Grand Rapids, MI	188,040	1.0 - 1.5%
Huston, TX	2,099,451	0.0 - 0.5%
Minneapolis, MN	422,331	0.0 - 0.5%
Philadelphia, PA	1,526,006	0.0 - 0.5%
San Francisco, CA	805,235	2.0 - 2.5%

Table 4.3: Company X User Density by City

In the table, each known city is listed with its associated census population and a field labeled "User Density". The "User Density" field (D_C), is calculated by dividing the "Total Company X Users" (N), by the "Census Population" (P) as shown in Equation (4.3).

$$D_C = \frac{N}{P} \tag{4.3}$$

This User Density figure gives an indication of Company X user concentration in each city. While it does not ultimately determine the likelihood of a Company X user walking into a given pharmacy, it does give insight into the penetration of Company X users into each city. Moreover, the metric creates a normalized method of comparing Company X user popularity across cities with varying populations.

Assuming that the number of retail pharmacies is linearly correlated to the population of each city, the User Density field can be leveraged to project the expected ping frequency. This does not give an indication of the total number of pings in a given city, but rather the likelihood that each store within that city will return at least one ping per day. The resulting metric is relative to the number of pharmacies in each city or region, but is sound given the assumption of linearity between city population and number of pharmaceutical retailers. Ping frequency can be projected on a distribution-level, or more simply through a binary threshold of zero or non-zero pings per day per store. Due to the significant number of compounding factors that likely affect the expected ping frequency distribution for retail pharmacies across each unique city, this capstone evaluates only the likelihood of locations generating zero or non-zero pings per day per store.

For example, the Cambridge experiment yielded a 75% likelihood of stores having greater-than or equal-to one ping per day. Cambridge, a few miles from Boston, can be loosely grouped within the Boston population given its close proximity under Company X's five mile population radius for user reporting. Therefore, the Cambridge population density is nearly 2%, as indicated in the Company X user density table. Equation (4.4) dictates how general, linear projections may be made between Cambridge and other cities based on the Cambridge pilot. L_B is Boston ping likelihood, L_C is target city ping likelihood, D_B is Boston user density, and D_C is target city user density.

$$\frac{L_B}{L_C} = \frac{D_B}{D_C} \tag{4.4}$$

Using Equation (4.4), Boston's ping likelihood ($L_B = 0.75$), and Boston's user density ($D_B = 0.190$), the Equations below are deduced, where P_C is user density as indicated in Equation (4.3):

$$\frac{0.75}{L_C} = \frac{0.0190}{D_C}$$
$$\frac{D_C}{L_C} = 0.0253$$

Therefore, the percentage of pharmacies generating at least one ping per day can be calculated for each city polled. A list of these cities and their associated percentage of stores with greater-than or equal-to one ping per day is shown in Table 4.4.

City	User Density	% of Stores > 0 Pings/Day
Atlanta, GA	1.5 - 2.0%	60 - 65%
Boston, MA	1.5 - 2.0%	75 - 80%
Columbus, OH	0.5 - 1.0%	20 - 25%
Denver, CO	0.5 - 1.0%	25 - 30%
Grand Rapids, MI	1.0 - 1.5%	40 - 45%
Huston, TX	0.0 - 0.5%	0 - 5%
Minneapolis, MN	0.0 - 0.5%	15 - 20%
Philadelphia, PA	0.0 - 0.5%	0 - 5%
San Francisco, CA	2.0 - 2.5%	80 - 85%

Table 4.4: Percentage of Stores with at Least One Ping/Day

The distribution of the small city subset above outlines a similar distribution pattern to the daily store ping data outlined earlier. Four of the cities sampled project less than 25% daily store inventories, three of the cities sampled project between 25 and 75% daily store inventories, and two of the cities sampled project greater than 75% daily store inventories. Clearly, this distribution of store ping data is skewed to the left. However, this data can only be used as an anecdotal projection. The number of cities sampled and specific sample conditions, constrained by the bootstrap sampling method, are too narrow to draw scientific conclusions from this type of projection. Moreover, the ping projections calculated directly conflict with Company X's reported most-populous cities.

Ultimately, the sponsor company must deploy a real-world trial, similar to the trial performed in Cambridge, MA, to truly understand the Company X inventory ping projections of each desired city. Despite the lack of scientific conclusions, these projections may provide general indicators of relational pings between different cities. For example, San Francisco and Cambridge both have very high ping data projections. Generally speaking, these cities tend to be infused with highly tech-savvy employees or students who may be more likely to have the Company X application. It is reasonable to believe that cities like these will have higher daily retail ping rates in comparison to Midwestern cities (such as Columbus, OH) and rural or suburban locations (such as Grand Rapids, MI).

4.1.4 Additional Considerations: Detection Range Variability

The initial Cambridge experiment was executed with the Company X Long tag model. As outlined in the Chapter 3, the sensing range of the Long model is 200 ft. To understand the impact of device sensing range on ping frequency, the team deployed an additional tag model into the field: the Company X "Short". The Short model has a sensing range of 150 ft, 50 ft shorter than the 200 ft range of the Company X Long. Additionally, the Company X Short is smaller, includes a non-removable battery, and provides an adhesive backing. Table 4.5 highlights the characteristic differences between the Company X Long and Short tag models.

Traker Model	Physical Volume	Battery Life	Sensing Range	Weight
Long	0.3 - 0.5 cubic in.	2 yrs.	200 ft.	0.2 - 0.3 oz.
Short	0.1 - 0.3 cubic in.	3 yrs.	150 ft.	0.1 - 0.2 oz.

Table 4.5: Company X Model Comparison: Long vs. Short

On February 1, 2020, the team deployed a total of six Short tags throughout Cambridge. These Shorts were dropped in the same method as the Long tags across three different stores (correlating to their respective Tracker numbers): Store 7, Store 13, and Store 17. Stores 7, 13, and 17 were chosen because they had the highest frequency of pings under the initial experiment and, therefore, would provide the highest volume of data. Over a period of 30 days between February 1, 2020 and March 1, 2020, the team collected data between both the Long tags and Short tags in the three target locations. The average pings per day per store are summarized in Table 4.6 below.

Store Number	Tag Name	Long	Short	Avg. Pings/Day
7	Long 7	X		18.14
	Short 7A		X	15.10
	Short 7B		X	18.59
13	Long 13	X		16.72
	Short 13A		X	10.03
	Short 13B		X	8.59
17	Long 17	X		25.95
	Short 17A		X	11.52
	Short 17B		X	29.76

Table 4.6: Company X Tag Ping Frequency Comparison: Long vs. Short

At a high level, the Short ping frequencies do not appear to be significantly different. Ultimately, a difference of means hypothesis z-test must be leveraged to statistically determine if there is a difference between the average pings per day of the Long tag and Short tag in each specific store. The data provided meets all requirements of a two-sided hypothesis test: the data is independent, the sample size is at least 30, and the sampling distribution is approximately normal. To simplify testing, an average of both Short devices (A and B) will be used to represent each store's Short ping frequency. Therefore, Equation (4.5) shows the established null hypothesis that there is no difference in ping frequency between the Long and Short pings for each store. The alternative hypothesis, as indicated in Equation (4.6), is that the ping frequency averages between tag models are not equal.

$$H_o : \mu_1 = \mu_2 \tag{4.5}$$

$$H_a : \mu_1 \neq \mu_2 \tag{4.6}$$

where μ_1 is the ping frequency average of the Long tag and μ_2 is the ping frequency average of the Short tag. Given the practical and low-risk application of this technology, a 90% confidence level is used to determine a sufficiency threshold. In order to reject the null hypothesis, the resulting z score for each store must be either in the top 5% of data or in the bottom 5% of data. As shown in Table 4.7, the correlating z values deduced for these values are 1.65 and -1.65, respectively.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545

Table 4.7: Positive Selection of Standard Z Score Values (Z Table, 2020)

Therefore, if the z score for a store is greater than 1.65 or less than -1.65, the Short data is statistically significantly different than the Long data. Using the population mean (μ), standard deviation (σ), and average pings per day (X), the associated z-score for each store is calculated using Equation (4.7) and displayed in Table 4.8.

$$Z = \frac{X - \mu}{\sigma} \tag{4.7}$$

Store Number	Tag Type	Avg. Pings/Day	Z-Score
7	Long	18.14	
	Short	16.84	-0.95
13	Long	16.72	
	Short	9.31	-4.33
17	Long	25.95	
	Short	20.64	-2.25

Table 4.8: Short Z Scores

As shown above, one store's z score falls within the acceptance range, while two do not. Store 7, with a z score of -0.95, shows no significant difference between the Long and Short model ping frequencies. In this case, we fail to reject the null hypothesis that the performance of the Long and Shorts are equal. Stores 13 and 17, however, demonstrate statistical significance with z scores of -4.33 and -2.25, respectively. For these stores, we reject the null hypothesis that the Long and Short models perform equally. Generally, the results are mixed. Due to the diverse results and minimal samples, a definitive conclusion cannot be made regarding whether the 50 ft. smaller read-range of the Short tag, or any other device, would make a significant change to inventory visibility levels. The sponsor company must weigh this uncertainty with other device characteristics and costs when determining the final device solution for its Product A retail inventory tracking solution.

4.1.5 Additional Considerations: The Dedicated Beacon Effect

While the inventory ping levels in highly-populated, urban areas appear to be sufficient for the sponsor company's needs, there is likely a significant decrease in ping frequency in rural or suburban areas. If capturing higher inventory snapshot levels in these areas is a priority for the sponsor company, one solution is to implement a dedicated beacon at retailer locations. This dedicated beacon, either an incremental subsidized cell phone, employee-downloaded Company X account, or other Bluetooth device, would provide retailers a dedicated resource to connect inventory tags to Company X's database. Although installing a dedicated beacon within a retail location was outside the scope of the Cambridge experiment, the experiment did organically create an opportunity to evaluate how much of an increase a dedicated beacon may provide retailers.

In evaluating the data for each store, the team reviewed all ping attributes for trends. One of these attributes was the "Client ID" associated with each ping. The client ID, according to Company X, is the non-identifying unique alpha-numeric account number associated with the device that creates the beacon ping between a Company X tag and its database at the time of connection. For example, when fictional Jane Doe downloads the Company X application on her cell phone, she is assigned a unique client ID - in this case we will call it 1234. Every time Jane's cell phone pings off of a Company X tag, that ping data includes her client ID of 1234, signaling that her phone is the one that connected to the tag. Throughout the data review process, the MIT team found that one client ID in particular had a significantly high number of pings. Moreover, all of its pings were associated with one location: Store 9. Based on the high ping frequency at one specific store, the team hypothesized that this client ID represented an employee at that location who happened to have the Company X app and was pinging the Company X tag while working. The first step to understand if this client ID was an employee was to map the distribution of its pings against the time of day. A cluster of pings consistently within an 8-10 hour time window may correlate to the user's shift schedule. This relative distribution is plotted in Figure 4.4 on a 24-hour scale, where 0 refers to the hour between 12AM - 1AM, 1 refers to the hour between 1AM - 2AM, and so on.

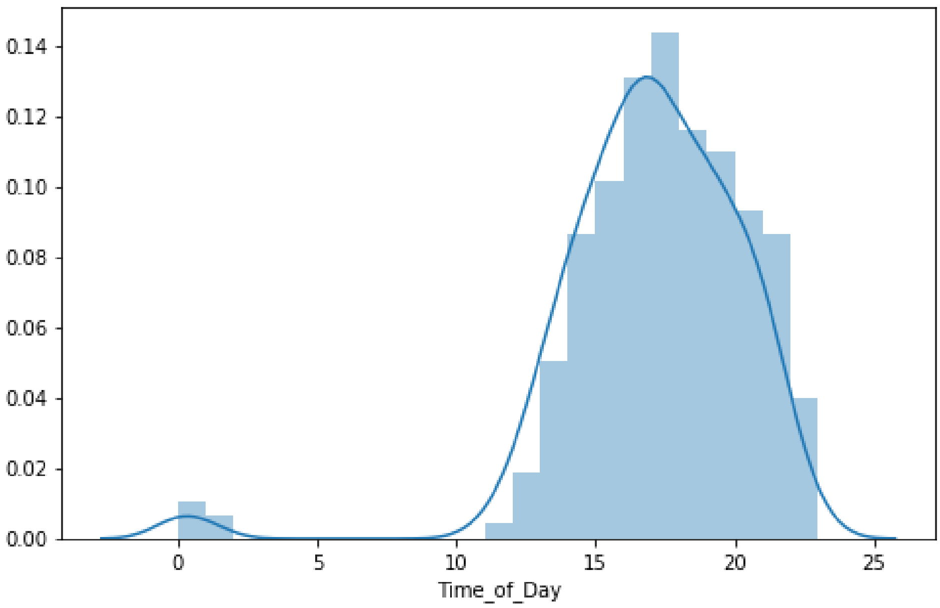

Figure 4.4: Client ID Time-of-Day Ping Distribution

As shown in Figure 4.4, the user's pings are clearly clustered during early-evening and nighttime hours. The average ping time is 16.97 (about 5PM) with a standard deviation of 3.36 hours. Assuming a normal distribution (based on visual inspection), 68% of the pings fall within a 6.72 hour range, and 86% of the pings fall within a 10 hour range. Additionally, the operating hours of this store are 8AM - 8PM, meaning about 20% of the user's pings occur outside of operating hours.

Furthermore, the individual's data can be evaluated on a day-of-week basis. Pings on certain days and not others may indicate an employment pattern, rather than shopping habits of a semi-regulated schedule with scattered frequencies across all days. The histogram in Figure 4.5 plots the percentage of the user's pings on each weekday, where 0 indicates Sunday, 1 indicates Monday, and so on.

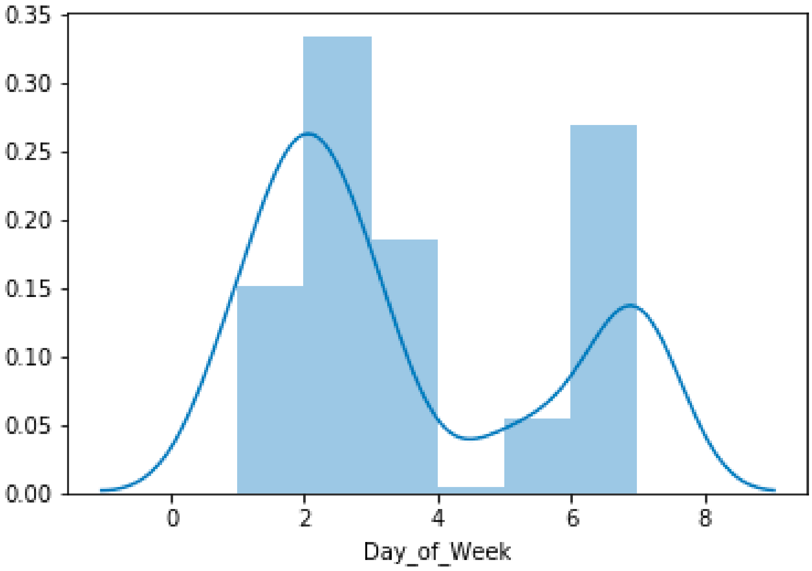

Figure 4.5: Client ID Day-of-Week Distribution

The histogram above demonstrates that the assumed employee creates pings at Store 9 on Mondays, Tuesdays, Wednesdays, Fridays, and Saturdays. As seen in Figure 4.5, no pings are seen on

Sundays and only one ping on Thursday, which technically stems from a late-night shift Wednesday night when the store was closed. The user's clustered time-of-day ping data, high frequency of after-hours pings, and defined weekday pattern provide compelling evidence that the user is, in fact, a store employee.

Including the suspected store employee's data, Store 9 averaged 7.44 pings per day. When excluding the store employee's data from the data set, Store 9 drops to an average of 2.80 pings per day. Without performing a hypothesis test, the employee's affect on Store 9's ping frequency is undisputed: the presumptive employee raises the store's average by nearly five pings per day. Albeit a small sample, this insight demonstrates the importance of the sponsor company's consideration of a dedicated ping device in low-ping retailer locations. Moreover, in the unlikely event that the studied user was not a store employee, the ping discrepancy undermines the fragility of data volume based on a single user.

Ultimately, the sponsor company's cross-functional groups including information technology, inventory management, and customer relations must understand what this ping increase is worth to the organization and appropriately incentivize its retailers to engage in beacon partnership.

4.2 Supply Chain Implementation Strategy

After evaluating the feasibility and proof-of-concept experimental data generated from the Cambridge experiment, the team moved to studying the supply chain implications from the proposed IoT technology solution. While Bluetooth was the main focus of the experiment and recommended technology solution, the following learning and applications are replicable across multiple technology offerings.

This implementation strategy aims to understand the impact of integrating a technological tracking solution within the sponsor's supply chain. The team conducted interviews with experts within each of the below sections, where applicable, to tailor its recommendations and learnings to the sponsor's current state supply chain operations. While the capstone was focused on the return on investment opportunity of a proposed technology solution for inventory visibility tracking, the findings and considerations outlined below are largely qualitative and will help move toward implementation in the near future. The sponsor is currently working on an adhesive application with Bluetooth technology similar to that of the Company X Short used in the Cambridge Experiment. While the final form factor and design is unknown, the below considerations and application recommendations should be universal to final device selection.

4.2.1 Customer Relations and Sales

Chapter 2 outlined the intricacies and interconnected nature of inventory management principles from hospital pharmacies to retail locations. While independent pharmacies define their own principles of inventory management, the relational aspect of communicating the inventory process impact to retailers is where the sponsor must be succinct and complete. Fully understanding each location's individual practices does not equate to the successful roll-out of the Bluetooth technology solution. Ideally, the final IoT solution must minimize or negate any change in the behavior of the end user, in this case the pharmacy employee. With this goal at the forefront of the design and technology selection, the impact to inventory management and handling principles should be minimal at the first stage of implementation. Further into the scaling of the technology, the sponsor may create a bipartisan relationship between themselves and their pharmaceutical customers by providing data insights and suggestions from a supply chain perspective based on inventory usage data.

Subsection 4.1.5 provided insights into the frequency of pings based on a dedicated beacon in a select pharmacy. This strategy to include a dedicated beacon device for a given pharmacy may be part of the implementation solution that the sponsor considers when scaling up its IoT solution. Even with the addition of a dedicated device, the proposed solution does not impact the relationship between the sponsor and the pharmacy. Understanding the current state of the individual customers will allow the customer relations team to tailor the conversation and impact to the customer to individual cases. This is a critical aspect of the implementation of an IoT device for inventory tracking. Understanding the customers' current technology infrastructure is also relevant when considering the necessary bandwidth and connectivity needs of the proposed solution and the ability of each customer location to support those needs.

The final aspect of communication that would be handled through the customer relations and sales teams would focus on the end state of the proposed technology. Deactivation, disposal, and other considerations are covered specifically in Subsection 4.2.9, but appropriate communication on the sponsor's final processes regarding the product's sale and end of inventory life will be crucial to consistency in interactions. Although the pharmacy expects no change to current procedures, the sponsor's plan to deactivate the Bluetooth technology for inventory visibility purposes will be part of the customer relation and sales organizations impact to the supply chain implementation success.

4.2.2 Procurement

With the final form factor of the Bluetooth technology solution still under consideration, multiple suppliers that currently provide solutions within the NB IoT and low-energy Bluetooth technology spaces may be considered. The ability of a party to successfully negotiate is significantly higher when it is far from reaching its deadline (Ishihara et al., 2006). As the sponsor approaches the procurement phase of implementing a new component into its supply chain, negotiation for contracts will be at the forefront of considering request for proposals (RFPs) developed by potential vendors. The first step in the procurement process is to assess the need for an RFP. This includes knowing the answer to three questions: 1) exactly what is needed in full detail, 2) is a current vendor already contracted to do similar work, and 3) how capable are the included vendors of resolving the proposed need (Hayhurst, 2017).

The sponsor should consider some of the following vendors, in addition to Company X, as it searches for Bluetooth devices that could be tailored to its needs: Zebra, DigiKey, and Honeywell. Through research and previous industry experience, these companies have the ability to tailor solutions to a client's needs and can produce at high volumes once a solution is defined.

After determining what price, discount, and delivery options are available, the sponsor's next step should be to identify the economic order quantity (EOQ) given its forecasted demand and inventory holding cost. This device will likely be a new stock keeping unit (SKU) and product to facilitate within the sponsor's supply chain operations. The procurement team should work with operations to define the appropriate level of cycle and safety stock to hold on-site for Product A implementation. Equation (4.8) depicts the standard EOQ formula

$$EOQ = \sqrt{\frac{2c_t D}{c_e}} \tag{4.8}$$

, where c_t is the cost of placing an ordering ($/order), D is the demand of the product in units/time, and c_e is the product purchase cost. Cost per order, c_t, takes into account the total cost to place an order including: receiving the shipment, processing the products, processing the invoice, auditing, labor, etc. The demand (D) of the product captures the total expected demand over a given time interval. The cost of holding excess inventory (c_e) includes the purchase cost of the product and the carrying or holding cost, which is the holding cost of inventory for a specific time period as a percentage ($/inventory $/time). Excess holding costs are different across industries and companies. Typically, it accounts for the cost required to hold inventory, including: shortage costs (warehouse space), service costs (insurance and taxes), risk costs (lost, stolen, damaged, obsolete), and capital costs (opportunity cost of an alternative investment) (Silver et al., 2017).

The integration of product details into the sponsor's ordering systems should be facilitated by gathering all pertinent product information from the selected vendor and developing new stock keeping unit affiliates with the information needed to process orders effectively.

4.2.3 MANUFACTURING

the sponsor company's Product A manufacturing processes are split into two categories: tablet and packaging. Tablet manufacturing includes the processes that convert raw materials into a Product A pill tablets for consumption. Packaging includes the processes that convert the Product A tablets into a final packaged good for sale. The final packaged good is commonly referred to as a Product A unit or finished good. The tablet manufacturing process is operated and controlled by the sponsor company. Packaging, on the other hand, is operated by a third party firm referred to in this paper as "Co-Packer". Given the scope of the IoT implementation as a packaging change and not a tablet change, the only manufacturing process affected by this change is Co-Packer's packaging operation. The MIT team was unable to obtain a technical interview with a Co-Packer representative regarding specific costs and considerations associated with adding IoT integration to its Product A packaging process. Although the addition of a minor IoT tracker to a box may seem simple, a host of packaging factors exist that the sponsor company and Co-Packer must consider. These considerations can be divided into two types: operational and strategic. Operational considerations include changes to Co-Packer's processes within the four walls of their packaging facility, while strategic considerations include the sponsor company's general approach to change management with Co-Packer.

Historically, when the sponsor company has proposed product or packaging changes, they have submitted formal change requests to the Co-Packer team. At that point, the Co-Packer team evaluated any incremental manufacturing expenses (labor, capital equipment, etc.) and built the costs into their pricing agreement with the sponsor company. In this case, there is a wide range of possibilities regarding manufacturing solutions for the proposed IoT device. A stand-alone tag, such as the Company X Long, would be simple to drop into a package and rely primarily on a minor change in labor spend. An adhesive tracker with built-in technology, however, may require additional automation and capital expenditure. Given the lack of interview and site access to the Co-Packer operational team, as well as the device form factor uncertainty, the exact change requirements to the manufacturing line are uncertain. The MIT team strongly recommends that the sponsor company and Co-Packer teams partner to leverage standard process mapping tools (such as Value Stream Mapping) and cause-and-effect tools (such as Failure Mode Analysis) to identify the technical requirements associated with the proposed IoT implementation.

Strategically, the sponsor company team must evaluate all internal stakeholders before proceeding with any packaging changes. Packaging changes may involve cross-functional teams ranging from marketing, regulatory, engineering, product operations, finance, and more. The MIT team advises the sponsor company to leverage a generally-accepted change management framework or defined internal process for such packaging changes before proceeding with any IoT device implementations. This type of inclusive approach, when leveraged rigorously, may save the organization significant time and financial waste in the future.

4.2.4 PACKAGING

Product A's packaging serves three primary purposes: protect/transport the tablets, advertise the product/company, and communicate FDA-required information to the consumer. When adding a foreign element (such as an IoT device) to an existing packaging design, analysis must be performed to forecast the change's impact on these three elements. In this case, adding a Bluetooth tracker will not reduce the packaging's ability to protect/transport the tablets nor will it interfere with the required FDA consumer documentation pamphlet. Rather, the device's most significant impact is likely to the product's external graphics.

According to one of the sponsor company's senior packaging engineers, all modifications to the packaging's graphics must be submitted through a formal change control process with the FDA. For an IoT implementation, this means any type of label or adhered tag must be formally submitted-to and approved-by the FDA before product implementation. Additionally, from an internal perspective, the sponsor company must ensure the consultation and approval of the technical packaging team. This inclusion will ensure that packaging drawings are updated accordingly and any structural changes or concerns are addressed and approved by the packaging experts before IoT go-live.

4.2.5 Transportation

As outlined in Chapter 2, the sponsor's existing supply chain network consists of manufacturing, shipment through the internal distribution center, and lastly to its distributors. According to one of the sponsor's Senior Supervisor, nearly all of the sponsor's Product A inbound shipments to the distribution center arrive via full truckload (Sponsor company, personal communication, 2020). Additionally, the sponsor claims that most of the sponsor's outbound shipments from the distribution center to distributors are shipped via full truckload (Sponsor company, personal communication, 2020). While parcel modes are leveraged for one-off orders and to meet peak seasonal demand, they only consist of about 10% of the distribution center's outbound shipments. Given the heavy emphasis of full truckload freight usage for Product A, the following transportation analysis will focus primarily on the full truckload mode. the sponsor must project the incremental cost of parcel shipments with more rigorous parcel data. The primary factors that influence an IoT implementation's effect on the sponsor's transportation business are cost and regulatory driven.

Adding an IoT device to Product A packaging will not affect the volume nor orientation of each Product A case. Moreover, it will not affect the layer pattern nor pallet configuration of each Product A pallet. The IoT device will, however, add weight to the finished product. Depending on Product A's transportation cost structure, this incremental weight increase may directly correlate to increased shipping costs to and from the distribution center. According to one of Product A's Channel Analytics Manager, each full pallet of Product A contains over 2,000 units of Product A. Furthermore, one truckload of Product A contains 20 - 25 pallets of product and cubes-out before it weighs-out (the truck's volume capacity is reached before it's weight capacity is). Given these figures, each truckload of Product A product contains over 50,000 units of Product A. If the sponsor company's truckload expenses are weight-dependent, the incremental cost from the IoT addition can be calculated by multiplying the weight of each IoT device by the total number of units per shipment. If, however, the sponsor company's shipments are priced independently of their weight, this incremental difference will not impact transportation costs. Rather, the sponsor company must ensure that the aggregated incremental weight of the final device does not result in exceeding the maximum weight capacity per shipment.

From a regulatory perspective, the sponsor company must consider the implications of shipping battery-powered devices with their products. If pursuing a device powered by rechargeable lithium-ion batteries, the sponsor company must ensure that proper labels are included at the case and pallet level. For example, the International Air Transport Association (IATA) mandates the application of a "Lithium Battery Mark and Overpack Statement" on every case shipment containing at least one lithium battery (IATA, 2019). While the IATA's title only specifically refers to its influence over air transport, it is also the governing organization of land freight shipment regulations. The IATA's labeling requirements by battery and shipment type are shown in Table 4.9 below.

Shipping Mode	Li content	Net quantity wt. of batteries per package	Battery Type			
AIR	0.3g to ≤1g/cell 0.3g to ≤2g/ battery	≤2.5 kg	L91, L92, L522	YES	YES	YES
	≤0.3g/cell	≤2.5kg	All Li Coin and 2L76	NO	YES	YES
	≤0.3g/cell	>2.5kg	All Li Coin and 2L76	YES	YES	YES
Land/ Sea only	All	All	All	NO	YES	YES

Table 4.9: Battery Shipment Label Requirements (Energizer, 2017)

At this point, Company X's Bluetooth trackers all use button cell batteries. This type of battery does not require specialized labeling at the time of this writing in 2020. Regardless of the final IoT device type, the sponsor company's supply chain team must evaluate any new labeling requirements for its cases that result from the addition of a battery-operated device.

4.2.6 Warehousing

Aforementioned in Subsection 4.2.5, the addition of a Bluetooth device will not change the orientation nor configuration of palleted products for the sponsor's warehousing operations. Inventory is currently managed through SAP, an enterprise resource planning and data management software. Through creating a new SKU for the Bluetooth technology, all weight and size information will automatically be associated with the product in SAP. While this doesn't change any of the manual operation flows and procedures of warehousing, it does increase the weight of the pallet. A standard, recycled wooden pallet has a capacity of 2500 lbs or approximately 1134 kg and a standard new wood pallet has a capacity of 3500 lbs or approximately 1588 kg (ULINE, 2020). With the additional weight of the Short tracker included per unit of Product A, the weight of the pallet increases by over 10 kg. This increases the total weight of the pallet of Product A to approximately 15% of the recycle pallet capacity and 11% of a new wood pallet's capacity. With this in mind, the additional weight would not affect the integrity of a wooden pallet used for warehousing operations. A consideration that would need to be evaluated is whether or not the pallet exceeds the accepted amount of weight to be moved by hand-truck or physical effort by the employee. The sponsor would then need to consider an ergonomic assessment of the incrementally heavier pallet with the Bluetooth technology included in the packaging material to determine appropriate warehouse transportation metrics given the change in the weight.

Given the adhesive application of the Bluetooth technology under consideration, minute impacts should be considered surrounding the overall size of the package. Additionally, the team's dimensional analysis shows that the technology solution will not impact the width, depth, or height of a normal pallet configuration of Product A. Warehousing a pallet will be no different operationally than it is today.

When it comes to warehousing at the wholesaler level, there needs to be a conversation facilitated around the changes in weight of the pallet and the addition of batteries to the previously battery-free pallets. Through interviews, it is understood that the sponsor currently ships product with batteries. This requirement stems from the need to track temperature for other products. Therefore, the sponsor has the existing infrastructure established internally to include the appropriate labels and documentation with Product A's future IoT devices. The wholesale distributor has also handled the sponsor's products with batteries included in the packaging, however this would be an additional product that also falls into that category and should be communicated accordingly.

4.2.7 Inventory

The addition of Bluetooth technology does not impact the current inventory processes that the sponsor currently follows. With a daily cycle count taking place, the addition of the stock keeping unit of the Bluetooth technology will be added to the list of products that are included in the cycle count. The value of the inventory will be increased incrementally by the factor of the increase of the cost of goods from the device addition. This increases the value of the inventory being held internally by the sponsor as well as the value of the inventory being passed through the wholesale distribution network.

To facilitate the addition of a new part to the final Product A product packaging, serializing the finished product offers the ability for the sponsor to track a specific Bluetooth device to a specific package of Product A through the supply chain. This will make the nightly cycle count at the distribution center more efficient. Additionally, there is no easy way to check if all products contain a Bluetooth device or not, especially during the transition phase. As product is made and the sponsor switches from Product A packages without a Bluetooth device to the future state of all packages including the technology for tracking, serialization of the final product will allow SAP to track this relationship through the entire supply chain from manufacturing to purchase of the product. Within the pharmaceutical industry, serialization of products allows for companies to ensure delivery of quality, genuine product to consumers as well as providing a closed loop end-to-end traceable network for all serialized product. This increased trace-ability will help the sponsor tackle its industry-wide counterfeit concerns (Shanley, 2017).

One of the sponsor's inventory managers mentioned that even though the sponsor's team gets daily inventory data from the wholesaler, there isn't specific detail regarding when, where, and how much inventory is sold to specific retailers nor hospitals through the wholesaler distribution network. The addition of inventory location data via the proposed Bluetooth technology infrastructure would allow for inventory teams to make strategic decisions regarding the shifting and purchasing of product. Not only does the inventory information of Product A impact how much and where the sponsor ships its products, it will ultimately travel upstream to facilitate the organization manage its raw goods inventory decisions when establishing manufacturing processes.

4.2.8 Distribution

Given the underlying distribution network outlined in Subsection 1.2.1, the movement of product from the manufacturing facility through the internal DC before heading to the wholesaler network is sponsor-owned inventory. After being passed through the wholesaler and into the final pharmacy locations, the sponsor is still responsible for the product but has no control of movement nor location. Its relationships with the wholesaler is a crucial aspect of realizing the full potential of the inventory visibility solution. Managing the relationship at the wholesaler level will unlock learnings and inventory opportunities in the final segment of the sponsor's supply chain. The communications and buy-in to the proposed solution should be managed similarly to the outline in Subsection 4.2.1. The wholesaler should receive the same information about the additional technology that the pharmacies do. This addition of technology does not impact the wholesalers' operations, and in theory, would give insights into inventory management practices and operations.

The addition of the technology solution is a win-win situation between the sponsor and their wholesalers as it can help manage the variability of demand and requests from the customer level. This partnership will help the smaller distributors maintain positive relationships with their customer base, especially those that do not currently use electronic data interchanges (EDI's).

Each distribution channel requires different levels of involvement based on the size of distributor and current state of the its relationship with the sponsor. As outlined in Subsections 4.2.5, 4.2.6, and 4.2.7, there is no expected disruption to current operation practices and standards for any of the stakeholders involved. One of the benefits of Bluetooth technology is that it does not require change in behavior from any of the levels of the supply chain involved, aside from the manufacturer. The mutually beneficial aspects of this technology solution for the sponsor and wholesale distributor should be at the forefront of the communication moving forward.

4.2.9 Point of Sale: Reverse Logistics vs. End-of-Life Disposal

Oftentimes, supply chain organizations underestimate the reverse logistics impact of new initiatives. For the sponsor company, the prioritization of IoT tag reverse logistics processes is paramount to project success. Moreover, given the project's impact on the sponsor company's retail customers, mitigating pharmaceutical disruptions or headaches is key to maintaining a positive relationship with key business partners. When evaluating various reverse logistics solutions, the sponsor company must avoid two critical pitfalls. First, the final solution must minimize the behavioral impact to all business partners involved in the distribution and sale of Product A. Driving change includes an increase in managerial resources and creates failure modes at each level: distribution, delivery, pharmacist behavior, etc. Second, the sponsor company must avoid actively tracking the Product A package beyond the point of sale. If a customer purchases a Product A package with an embedded IoT tracker and leaves the retail location, the sponsor company can no longer track the package. This raises serious consumer privacy concerns in addition to data accuracy concerns regarding location inventory. Additionally, the sponsor company must consider the environmental impact of the IoT tracker's end-of-life journey, however this consideration is explored in Subsection 4.2.10.

With the above considerations in mind, the sponsor company has three strategic options regarding IoT device handling at the pharmaceutical level. The first option is to have retail pharmacists remove the IoT tracker from the Product A packaging and dispose of the device appropriately. This option requires behavior changes by thousands of pharmacists at retail locations across the country, both in inventory handling practices and in tracker disposal infrastructure. Furthermore, the consequences of human error may result in serious legal ramifications (from tracking consumers with un-removed IoT trackers). Therefore, pharmacist tracker removal and disposal is not a viable option.

The second option is for pharmacists to remove the IoT device and ship it back to the sponsor company for product reuse. While the financial and environmental benefits of this option are significant (cost of goods savings and reduced landfill contribution), this strategy also violates one of the project's primary concerns: to avoid a change in human behavior. Not only does this strategy require a change in pharmacist behavior, it would require the establishment of a reverse logistics product flow that does not currently exist. The only flow of goods from pharmacies to the sponsor company are product returns via parcel shipments. This type of infrastructure is financially and environmentally insufficient for hundreds of thousands of IoT devices to be shipped and handled from thousands of retail locations to the sponsor company.

The third option is for the sponsor company, distributors, and pharmacists to do nothing. In this case, the IoT device (embedded in the Product A packaging) would remain in the packaging at the point of sale and proceed to follow the consumer as they depart the retail location. Clearly, this solution raises serious privacy questions: would the sponsor company have visibility to consumer location beyond the point of sale? If so, is that legal? Will consumers continue to purchase the sponsor company's products if they knew what information the sponsor company had? Do consumers trust the sponsor company with their location information? In order to mitigate the damaging consumer and business ramifications of these questions, the sponsor company must implement a fail-safe method to ensure it does not have consumer location information beyond the point of sale. To understand how this may be accomplished from a technical perspective, the MIT team conducted an interview with a Company X engineering representative. Given the information obtained from Company X, the MIT team recommends that the sponsor company pursue one of two options for clearing its IoT device visibility: device geofencing or beacon filtering.

With the device geofencing option, the sponsor company may partner with Company X to create a database of all of its retail pharmacy locations. Company X's technology team has the ability to create a geofence around each retail location and only share tag information with the sponsor company for its IoT tags that are within a predetermined range of those addresses. Under this strategy, Company X would have all of the tag data stored in its database, but only communicate ping data to the sponsor company for its IoT tags at retailers included in the sponsor company's provided retailer database. The programming algorithms required for this solution are not simple, according to Company X, but are feasible under the right contractual arrangement between the sponsor company and Company X (Company X, personal communication, 2020).

The beacon filtering option, however, is much simpler from a technical perspective (Company X, personal communication, 2020). Under this strategy, the sponsor company must implement a dedicated ping beacon at each retail location as suggested in Subsection 4.1.5. If the sponsor company were to implement a dedicated ping beacon at each retail location, Company X could filter the ping data the sponsor company receives based on the user it comes from. As outlined in Subsection 4.1.5, this field is already collected by Company X and is called the "Client ID". Similar to the device geofencing option, this solution would require a contractual arrangement between the sponsor company and Company X but would likely come at a reduced cost with lower algorithmic complexity (Company X, personal communication, 2020).

The MIT team urges the sponsor company to pursue one of the "third" options listed above. Ultimately, the sponsor company must decide whether or not to implement the dedicated retail beacon solution. Based on its beacon infrastructure decision, the sponsor company can implement the appropriate end-of-life tracking solution to protect its brand integrity and consumers' data.

4.2.10 Environmental, Health, and Safety

It is critical for the sponsor company to account for the environmental, health, and safety risks associated with its final end-of-life strategy. In general, IoT tracking devices do not contain a significant amount of hazardous material. At the time of this writing, the only component of Company X tags that poses an environmental, health, or safety risk is the battery. As of 2020, the United States has a series of strict regulations regarding proper battery disposal procedures. These measures are designed to protect the environment and the people who handle battery waste streams. The accepted and prohibited disposal methods for batteries are dependent on the type of battery based on the chemicals it contains: lithium, lithium-ion, lead, etc. Currently, the Company X Long and Short models implement a 3V Lithium battery (Company X, personal communication, 2020). This type of battery is commonly referred to as a "coin", "watch" (due to its use in wrist watches), or "button cell" battery. A cross-sectional example of this battery type is depicted in Figure 4.6.

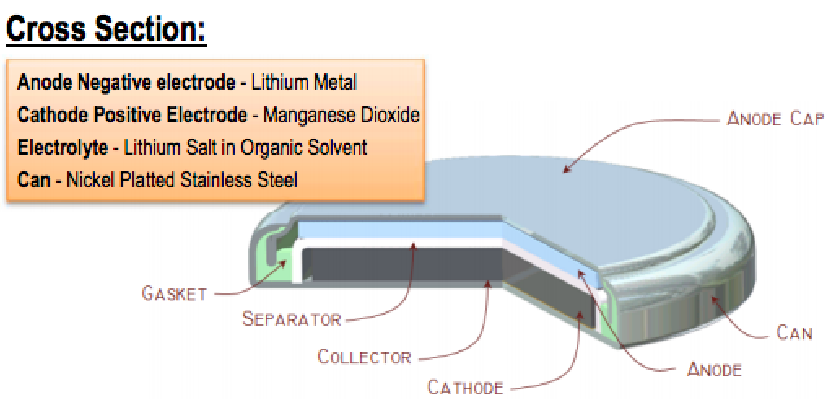

Figure 4.6: Coin Battery Cross Section (Energizer, 2017)

Given the low levels of lithium and lack of hazardous chemicals in these battery types, they may be disposed of using standard landfill procedures (Energizer, 2017). Under the current Company X product design, the sponsor company does not need to take any additional measures to ensure its Product A packaging, with embedded IoT tracker, is disposed of properly. However, the battery type and design of the final IoT device must be considered to ensure all battery regulatory procedures are followed appropriately.

4.2.11 Legal

An underlying assumption throughout the Cambridge experiment was that the sponsor company's collection and use of inventory location from naive Company X users was legal. This is, in fact, true. Upon download and use of the Company X application, all users must consent to the Company X Terms of Service, which states that users understand Company X's Privacy Policy (Company X, 2019). Moreover, Company X's Privacy Policy explicitly states its right to create and use anonymized user data. As outlined in its Privacy Policy, the sponsor company is a third party between Company X and its customers. However, given the acceleration of technical capabilities and increasing privacy concerns from consumers, the sponsor company must continually review Company X's Privacy Policy for any changes to ensure it is compliant. Additionally, as state and federal governments become more involved in consumer data legislature, the sponsor company's legal team must continually review the appropriate governmental regulations regarding its inventory data collection processes within all of its operating states and countries.

4.2.12 Incubation Team and Operations

The sponsor's operation and innovation teams is where the IoT project originated. The team is operationally responsible for ensuring the proposed technology solution is appropriately integrated and delivers the results that the sponsor needs. As discussed in the previous sections, the impact to operations internally will have to be communicated efficiently and effectively. Another aspect to the deployment of this solution is identifying changes, if any, to the key business and operations leaders' daily tasks. Bringing them along and providing the support necessary to answer questions and work through the new-look supply chain processes should be a key focus for the team early on in the roll-out.

Financially, individual line items need to be fully vetted and analyzed against the original plan as the project moves through the development stages and into design. Factors such as direct labor, subcontracted work and support services, hardware, software, training, and consultancy support that affect the overall project success both operationally and financially.

In terms of managing the change aspects that come with a project of this scale, the sponsor must consider every aspect of the proposed technology from communication to the business through the level of complexity of change needed and execution. The integration of IoT technology in the pharmaceutical space brings about new possibilities for interactions between systems while also developing new options for the business to understand impact to service and customers through new tracking capabilities (Košťál et al., 2019). The steps for turning innovative ideas into realizable solutions is creating the environment for adapting, planning for adoption, integrating technology into the workflow, spreading the understanding, and sustaining the change (Yeole & Kalbande, 2018).

Organizational change involves the ability to respond to internal and external challenges that arise from ideation through implementation. Creating an atmosphere of pro-active engagement and positivity will create an environment of fixing, rather than identifying, issues. Understanding the balance of controllable elements that influence change (internal) and the unidentified challenges (external) allows the business to define realistic goals and formulate recommendations for addressing issues during implementation (Năstase et al., 2012).

This Bluetooth technology implementation project seems to follow the constructs of a waterfall model. Figure 4.7 depicts the categories typically outlined and discussed during the development of a change management project implementation.

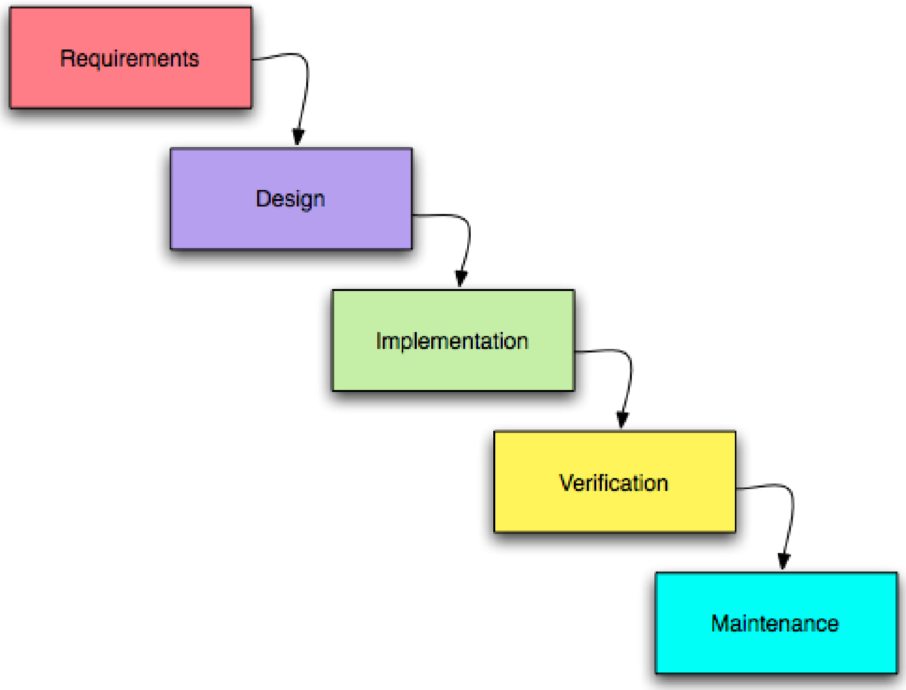

Figure 4.7: Waterfall Model (Hughey, 2009)

The Cambridge Experiment was a small trial version of this methodology up through the testing phase. On a larger scale, the requirements phase has already been developed and should be constantly communicated and referred to as the backbone of the rationale behind the project. The sponsor is currently in the build phase of this approach as the outline for specific design specifications for the Bluetooth tracker have been previously identified, and tested, in the experiment. Moving into the implementation phase will require the integration of the aforementioned layers of the sponsor's supply chain network. The sponsor will need to evaluate the complexity of implementation but fully understand the change in operations and requirements of impacted stakeholders. Inherently, with the addition of a new technology, there is a layer of training that has to be created and incorporated at each level to make sure that expectations are clear and readily accessible. Another key aspect of the implementation phase is an appropriate scale-up plan beyond the small trial scenarios that the sponsor can control from start to finish. Using a smaller trial scenario will allow the project to truly be verified. This is usually a phase that is skipped in real-world applications as projects are implemented and companies immediately move into sustaining rather than iterating and improving.

Identifying all of the entities that are interrelated and what connections they have will allow for problems to be handled accordingly as implementation begins. An example framework can be seen in Figure 4.8.

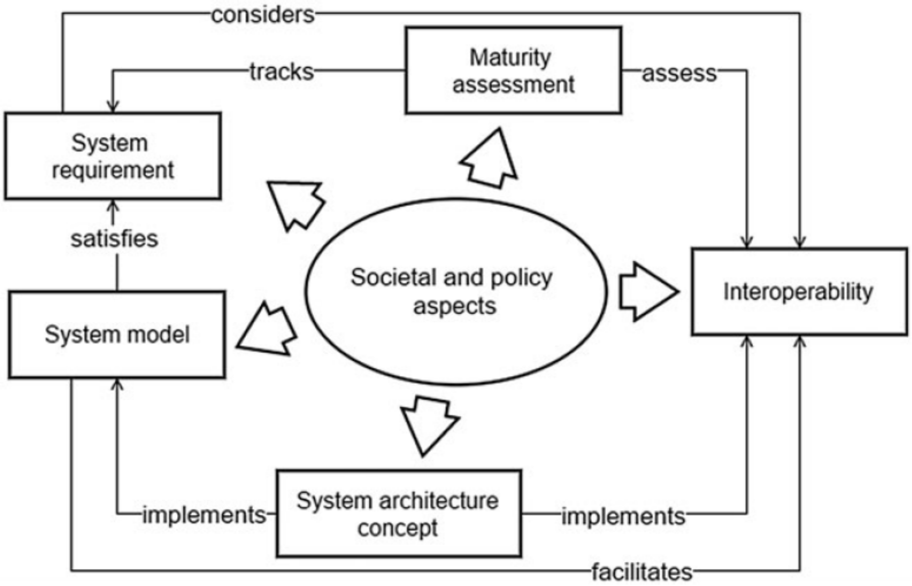

Figure 4.8: IoT Implementation Framework (Zdravković et al., 2018)

A strategic project timeline should be at the core of the execution phase to hold the internal team accountable to deadlines and keep the project moving at a steady pace. This process rigor will build momentum within the organization, and in this scenario, with external stakeholders that are impacted by the proposed solution.

5 Conclusion

In Summer 2019, the sponsor approached MIT with a question: does an economical and practical IoT inventory-tracking solution exist to mitigate consumer risk and existing corporate financial waste streams? Over the course of eight months, this study analyzed the technology and supply chain implications of various inventory IoT tracking solutions. Beginning with an in-depth technology review, the team identified that Bluetooth technology would provide the sponsor with the most practical and cost-effective solution to meet its pharmaceutical retail needs. In a proof-of-concept study, the team physically deployed Company X tags across 19 Cambridge locations to understand the technology's feasibility and simulate inventory snapshots of Product A. Through a rigorous analysis of this experiment's results and cross-functional supply chain analysis, the team was able to provide the sponsor with guidance regarding IoT network design and supply chain implementation. Using this analysis as a springboard, the sponsor's future implementation of IoT tracking technology can create differential revenue and waste reduction opportunities for Product A.

5.1 Technology Insights and Recommendations

The sponsor should pursue a Bluetooth-based IoT network for its retail pharmacy inventory tracking needs. In 2020, Bluetooth devices are the cheapest and smallest type of tracking device that does not mandate a beacon. Moreover, Bluetooth's low barrier to entry makes the technology accessible to more business ventures. This accessibility has created a wide range of companies, such as Company X, offering Bluetooth tracking devices in various form factors and applications. The array of device types, network infrastructure options, and service providers makes Bluetooth the clear IoT platform choice.

Regarding the sponsor's particular application, the Cambridge experiment provides evidence that Bluetooth IoT tracking is feasible in the retail pharmacy environment. Without dedicated beacon assistance, individual stores averaged over 5.1 inventory snapshots per day and 75% of locations averaged over 1.0 pings per day. While significant work is left to be done, the experiment's results were positive. Bluetooth's established community of users and business platforms, along with the successful experiment, support the conclusion that the sponsor company pursue a Bluetooth-based inventory tracking solution.

5.2 Supply Chain Management Insights and Recommendations

The sponsor should begin with developing a project timeline before addressing any of the change management principles that are associated with the Bluetooth technology implementation. Developing a schedule with well-coordinated and detailed deadlines will allow for the compelling message and stakeholder engagement sessions to have an underlying backbone. Key stakeholders and business leaders need to be integrated as the complexity of the change is evaluated and appropriate measures are defined for defining project success and implementation. Customers and external partners need to be brought in at the appropriate time to ensure the requirements for success are met.

In relation to the sponsor's specific operations and impact, the impacts outlined in the Chapter 4 provide a guideline to integrating the proposed Bluetooth technology supported by the experiment and research conducted in Chapter 2. While section 4.2.12 provides insights from other IoT implementation projects found in literature and through past experiences, the specific application to the sponsor's internal business structure will require some manipulation and specific considerations outside of what is suggested.

5.3 Future Research

While this study revealed meaningful insights into the possibilities of Bluetooth inventory tracking for the sponsor, a significant number of questions must be answered before a financial investment is made into this project.

From a technology perspective, the sponsor must identify the right business partner to provide a Bluetooth network and device, or solely a network to support a third party device of its choosing. Additionally, the sponsor must identify a Bluetooth IoT tag that is low-cost, wide read range, and minimally disrupts Product A's secondary packaging. This device may be either an off-the-shelf item (such as the Company X trackers used in the experiment) or a custom tag created by an engineering vendor for the sponsor's unique application. After identifying its tag and network infrastructure, the sponsor must decide if or how to leverage a beacon strategy at retail locations. As evidenced in Section 4.1.5, partnering with retailers to invest in a dedicated beacon solution may significantly increase the level of inventory visibility in rural and suburban environments.

Regarding the sponsor's supply chain considerations, a thorough change management analysis must be performed to capture the project's impact on each level of the organization. The sponsor must either leverage an existing internal protocol for supply chain change management initiatives or identify a framework that has been successfully implemented for similar projects across other industries. Most importantly, this framework must include the impact to the customer and consumer. While retailers and consumers are not directly part of the sponsor's supply chain, they are the lifeblood of its business model. Failure to include these stakeholders would prove catastrophic.

Lastly, the sponsor must consider future applications of this technology before any initial investments are made. While Product A that was used for this experiment may be today's promising product, consumer preferences and global health needs may shift future demand. Building flexibility into its tracking device, network infrastructure, and supply chain system will allow the sponsor to maintain agility with its final inventory tracking solution. This flexibility will allow the sponsor to sustain, and even increase, its supply chain competitive advantage.

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