THE PHARMACEUTICAL SUPPLY CHAIN AND THE INTERNET OF THINGS

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1 Introduction

Throughout history the pharmaceutical supply chain has grown from an unregulated process, to a digitally recorded network of information. Regulatory and legal requirements have mandated traceability of product which has sparked an era of networking technology throughout the pharmaceutical industry. These technologies have given organizations the ability to share data, track shipments, management inventory, and more. Capitalizing on technological advancements has been a burden for some organizations, proving to be both an operational and financial challenge. Even though there has been tremendous progress made towards fully integrating the pharmaceutical supply chain through networking technologies, examining the technological maturity of the supply chain through the lens of current events begs to question its sufficiency.

2 History of the Pharmaceutical Industry

The earliest starting point of the pharmaceutical industry can be considered during the middle ages, a time of apothecaries and often unreliable folklore treatments (Walsh, 2010). Another origin of the pharmaceutical industry can be seen from dye and chemical companies, and their identification of medicinal application of chemicals (Daemmrich & Bowden, 2005).

A pharmaceutical industry that would be more recognizable and easier to compare to the one we have today began to emerge in the late 1600s and early 1700s, with patented production and selling of medicinal stuff (Walsh, 2010). The mid-1800s saw increased growth in pharmaceutical production from companies such as GlaxoSmithKline and Pfizer (Walsh, 2010). Pfizer itself played a key role during the Civil War, producing pain killers and antiseptics to be used by soldiers (Walsh, 2010). The remainder of the 18th century brought continued efforts to start medicinal manufacturing and R&D factories (Walsh, 2010).

Two noticeable achievements were made in the pharmaceutical industry during the early 1900s involving insulin and penicillin (Walsh, 2010). Fredrick Banting, in collaboration with colleagues and scientists from the company Eli Lilly, discovered how to isolate, and industrially produce and distribute insulin for the treatment of diabetes (Walsh, 2010). Brostoff, Keen, and Brostoff describe two eras of diabetes in the 1900s: the Pre-Insulin Era from 1897-1922; the Insulin Era from 1922-1945 (2007). During the Pre-Insulin Era, on average a ten-year-old child diagnosed with diabetes had approximately two years of life remaining from the time they were diagnosed (Brostoff, Keen, & Brostoff, 2017). Adults aged thirty and fifty diagnosed with diabetes during the Pre-Insulin Era had approximately five and nine years of life remaining, respectively (Brostoff, Keen, & Brostoff, 2007). At the peak of the Insulin Era (1939-1945), the average expected remaining life for each age of diagnoses increased to approximately forty-five years, thirty years, and sixteen years, respectively for patients aged ten, thirty,

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and fifty (Brostoff, Keen & Brostoff, 2017). According to statistics from the American Diabetes Association, 34 million children and adults have diabetes in the U.S., with another 1.5 million diagnosed on average every year (American Diabetes Association, 2018).

The second achievement of the early 1900s was the mass production of penicillin to be used for soldiers during World War II (Walsh, 2010). This mass production was a government-supported project, involving international efforts from Merck, Pfizer, and Squibb pharmaceutical manufacturing companies (Walsh, 2010). Discovered in 1928, penicillin was first used in 1942 to treat a patient for blood poisoning (Rothman, 2016). At the time the single treatment consumed half of the available penicillin in the United States as scientists relied on extracting penicillin from mold, having not yet figured out how to synthetically derive it (Rothman, 2016). By 1944 however, enough penicillin was being produced to treat not only soldiers on the battlefield, but civilians in the U.S. as well, a remarkable increase in manufacturing capabilities (Rothman, 2016).

The 1900s also saw improvements in regulation. The authorized licensing of medicine manufacturers by the U.S. Hygienic Laboratory was put into place under the 1902 Biologics Control Act ((Daemmrich & Bowden, 2005). Additionally, the 1906 Food and Drugs Act in the U.S. and similar laws throughout the EU "forced manufacturers to reveal ingredients on product labels" on medicine (Daemmrich & Bowden, 2005).

Despite these improvements and legislative regulations in the early 1900s, by the start of the 1930s, most medicine was bought without a prescription and was compounded (mixed and prepared to the patient's needed dosage) manually by pharmacists (Daemmrich & Bowden, 2005). The continued lack of regulation of the production and administration of medicine created an opportunity for professional bodies (physicians associations, pharmacists' groups, etc.) to set manufacturing standards which provided guidance around quality production processes (Daemmrich & Bowden, 2005). These groups even "exposed fallacious claims made concerning medical ingredients" (Daemmrich & Bowden, 2005).

In the mid-1900s, The UK's National Health Service (NHS) increased structure and standard regarding prescription drugs and increased investor incentives (Walsh, 2010). In the U.S., government funding brought forth the National Institute of Health, fueling pharmaceutical development (Walsh, 2010). This increase of government funding and financial investment in the pharmaceutical industry quickly brought into question the ethics behind for-profit medicinal production as the end of WWII did not see a decline in pharmaceutical advancement, but rather a rapid growth (Walsh, 2010).

The late-middle-half of the 1900s brought a boom in pharmaceutical discovery (Daemmrich & Bowden, 2005). Scientific breakthroughs were made to develop things such as "synthetic vitamins, sulfonamides, antibiotics, hormones…, psychotropic drugs, antihistamines, and new vaccines (Daemmrich & Bowden, 2005). The 1960s brought the contraceptive pill and a new class of psychological medicine (Walsh, 2010). It was during this period that the U.S. developed safety regulations for drug manufacturing, in response to manufacturing incidents (Daemmrich & Bowden, 2005).

The 1937 sulfanilamide incident took place when a scientist working at S. E. Massengill developed a new drug without conducting any animal testing or researching literature on the ingredients used in the compound (Daemmrich & Bowden, 2005). The scientist's lack of testing and lack of research resulted in the deaths of over one hundred patients (Daemmrich & Bowden, 2005). The U.S. government responded to public outrage by rapidly approving the 1983 Food, Drug & Cosmetic Act, expanding the FDA's oversight on new drugs (Daemmrich & Bowden, 2005). The FDA now required companies to conduct thorough testing, and after review of those results the FDA could reject a company's request for drug approval, protecting patients from dangerous medicine consumption (Daemmrich & Bowden, 2005).

The period between 1960 and 1980 saw continued scientific advancements in medicine, combatting difficult diseases such as cancer and Parkinson's (Daemmrich & Bowden, 2005). These advancements brought more of the public's attention, as evidenced by Senator Estes Kefauver's investigation into the cost versus price of pharmaceutical manufacturing and company's marketing strategies (Daemmrich & Bowden, 2005). During the time Kefauver's investigation was taking place in the U.S., the 1961 thalidomide consumption caused severe birth defects in roughly ten thousand children worldwide (Daemmrich & Bowden, 2005). The thalidomide sedative did not undergo thorough testing before it was made commercially available (Daemmrich & Bowden, 2005). Although thalidomide was not consumed in the U.S., the government responded in 1962 by adding the Kefauver Harris Amendment to the FDA's set of rules (Daemmrich & Bowden, 2005). This amendment would require "proof of efficacy and accurate disclosure of side-effects for new medicines", and detailed approved methods for testing (Walsh, 2010; Daemmrich & Bowden, 2005).

In the 1980s the industry continued to experience scientific advancements, focusing on biotechnology, treatments for diseases like cancer and HIV/AIDS, and gene therapies (Daemmrich & Bowden, 2005). Responding to these potential drug offerings, consumers demanded more research and an expedited drug approval process (Daemmrich & Bowden, 2005). An outcome of this was the Orphan Drug Act of 1983, which was designed to promote investments in researching and developing medicine to treat rare diseases, and diseases that have a small or limited patient population (Daemmrich & Bowden, 2005; Swann, 2018). Similar in ideal to the Orphan Drug Act, the 1984 Drug Price Competition & Patent Term Restoration Act, or Hatch-Waxman Act for short, was put in place to allow the FDA the ability to approve generic medicine without additional testing or research (Walsh, 2010; Daemmrich & Bowden, 2005). This act has allowed generic medicine production to grow alongside the industry's growth and demand for medicine.

The late 20th century and into the early 21st century, dozens of noteworthy company mergers took place across the pharmaceutical industry, linking organizations internationally (Daemmrich & Bowden, 2005). This gave way to the major brand names we know today, and set the stage for the global pharmaceutical supply chain we rely on today.

3 The Pharmaceutical Supply Chain

There are four distinct players in the pharmaceutical supply chain: manufacturers, distributors, retailers, and patients (Dabora & Turaga & Schulman, 2017). Some authors, such as Kapoor and Dadarwal, describe even more players listed out like government agencies, hospitals, clinics, research organizations, and the FDA (2018). Adding to the complexity of the pharmaceutical supply chain, many organizations manufacture, manage, or work with a variety of products from prescription drugs to biologics (Kapoor & Dadarwal, 2018). Shabbir Dahod, President and CEO of TraceLink, Inc., describes the pharmaceutical supply chain as "complex" and "multi-tiered", presenting vulnerabilities throughout the supply chain process (2017). Reference Figure 1 for a breakdown of TraceLink's view of the pharmaceutical supply chain.

Looking at the start of TraceLink's in-depth view of the pharmaceutical supply chain, a brand manufacturer is the organization whose brand name is associated with a non-generic drug (Pharmaceutical Commerce, 2017; Quinn, 2012). Brand manufacturers, or brand owners, rely on contract manufacturing organizations (CMOs) to support more affordable scale-up costs and expedited time to market (Quinn, 2012). The relationships between these two business types throughout the pharmaceutical industry is not without its own challenges (Quinn, 2012). CMOs tend to overcommit on deliverables to brand owners, not taking into account the unpredictability of pharmaceutical

manufacturing and product demand (Quinn, 2012). Experts encourage brand manufacturers and CMOs to collaborate more effectively, plan ahead together, and align expectations for quality (Quinn, 2012). "Collaboration and agreement on critical metrics throughout the lifecycle of a product provides a mechanism to adapt to changing requirements" (Quinn, 2012).

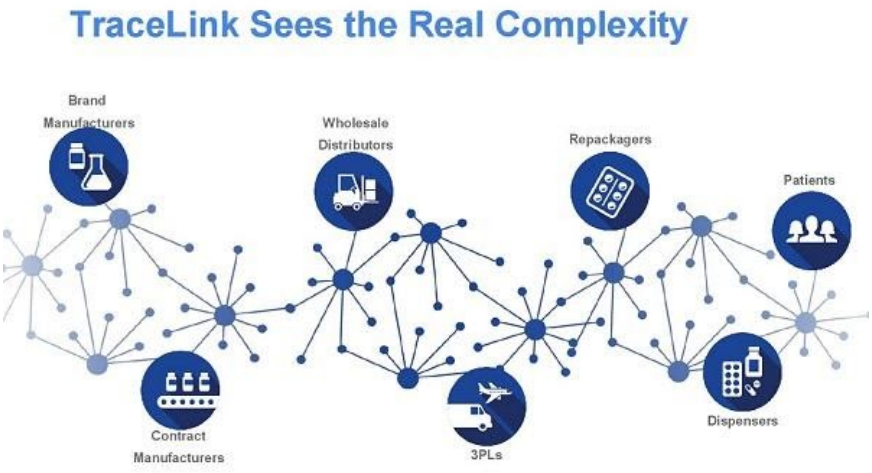

Figure 1: The pharmaceutical supply chain. *Source: TraceLink, Inc.*

The role of wholesalers is important in the pharmaceutical supply chain. A wholesaler gives pharmaceutical manufacturers the ability to ship mass quantities of product (Olson, n.d.). Storage, distribution, repackaging, and other services remain the responsibility of the wholesaler, rather than the manufacturer (Olson, n.d.). Wholesale distributors handle approximately 91% of all revenue-generating pharmaceutical products (Dabora & Turaga & Schulman, 2017). In the U.S. the pharmaceutical wholesaler market is cornered by three big organizations (AmerisourceBergen, Cardinal Health, and McKesson) each of which has been involved in legal proceedings (Dabora & Turaga & Schulman, 2017; Stempel, 2018; Department of Justice, 2017; Weis, 2016).

In 2016, Cardinal Health was charged a total of $44 million worth of civil penalties for failing to report suspicious pharmaceutical supply chain activity taking place within their purview (Weis, 2016). The penalties against Cardinal Health were also for their failure to maintain good documentation and manufacturing records (Weis, 2016). McKesson violated the Controlled Substance Act in 2008 and was charged $13.25 million in civil penalties (Department of Justice, 2017). Not having learned their lesson, the distribution giant committed similar violations of the Controlled Substance Act again in 2017, owing $150 million in civil penalties (Department of Justice, 2017). Out of the three leading wholesale distributors' illegal activities, those of AmerisourceBergen were arguably the worst.

Between 2017 and 2018, AmerisourceBergen was charged a total of $885 million in civil fraud charges, fines, and forfeitures (Stempel, 2018). As a distribution company also responsible for repackaging, AmerisourceBergen was using the "overfill" from original drug vials to refill new ones (Stempel, 2018). This falsely yielded higher production, resulting in an approximate profit increase of $99.6 million dollars (Stempel, 2018). AmerisourceBergen also shipped millions of chemotherapy treatments that were packaged in unsterile conditions (Stempel, 2018). Lastly, they billed multiple doctors for the same dose of medication, allowing them to receive duplicate payments (Stempel, 2018).

Moving through the supply chain, third-party Logistics, or 3PLs for short, add another layer to the supply chain by specializing in distribution logistics such as order fulfillment and shipment strategy

(Davo, 2018). Pharmacies buy from wholesalers under a contract in which the wholesaler agrees to keep the pharmacy stocked to meet demand (Olson, n.d.). With all these variables, layers, and bad actors present in the pharmaceutical supply chain, it is not surprising there are so many cases of substandard drug consumption.

Substandard drugs are any drugs that are not manufactured with good quality, are not safe for patient consumption, or do not offer any therapeutic value to patients (Jahnke, 2017). Substandard drugs can be described as counterfeit, contaminated, or ineffective (Jahnke, 2017). It could take weeks or even months for a patient to recognize the lack of therapeutic effects from their medicine (Jahnke, 2017). Because of this, it is difficult for researchers to fully report the true financial impact of poorly manufactured or counterfeit drugs (Janke, 2017). It is even more difficult to accurately report how many deaths have been the result of substandard drugs (Jahnke, 2017). Studies have been conducted to quantify this number and as an example, it's believed that hundreds of thousands of African children have died due to poor-quality malaria medication (Jahnke, 2017).

In 2012, Pakistan experienced the death of over 200 citizens to counterfeit drugs (Jahnke, 2017). The investigation around the deaths revealed that each individual was being treated for high blood pressure, relying on hypertensive medicine for treatment (Jahnke, 2017). Investigators looked into these patients' medication and discovered, after thorough testing conducted in vetted British laboratories, the medication had been contaminated with an anti-malarial (Jahnke, 2017). When combined with the medicine's other ingredients the anti-malarial reacted negatively, leaking itself into the bone marrow of patients in deadly amounts (Jahnke, 2017).

Another substandard drug incident occurred in 2012, when back-pain treatment medication was contaminated with a fungus at the New England Compounding Center in Massachusetts (Jahnke, 2017). The fungus was identified as *Exserohilum rostratum* which is a form of human-based meningitis (Casadevall & Pirofski, 2014). An investigation conducted by the CDC, the FDA, and other healthcare organizations determined that the back-pain medication (methylprednisolone injections) had been contaminated with the fungus due to the New England Compounding Center's horrifically lacking lab practices (CDC, n.d.; Lupkin, 2014). Instances of falsified records, the wrongfully justified use of expired materials, and the lack of recall requests on contaminated products are listed in indictments against the New England Compounding Center and its employees (Lupkin, 2014). The outbreak was so widespread over seven hundred people experienced severe illness, of which over sixty were fatal (Lupkin, 2014). The owner of the New England Compounding Center, Barry Cadden, was arrested and charged with second-degree murder for the deaths of twenty-five victims (Lupkin, 2014).

In the case of the New England Compounding Center's contaminated drugs, sixty deaths pales compared to what Shabbir Dahod believes to be roughly one million deaths a year caused by counterfeit drugs worldwide (2017). He warns that counterfeit drugs do not discriminate, affecting all drugs types and impacting all patient types, from cancer to diabetes to over-the-counter generics (Dahod, 2017). Shabbir defines "counterfeit drugs" as products not made by a drug manufacturer, forcefully inserted into the pharmaceutical supply chain by a counterfeiter, and product that is ineffective in treating patients (Dahod, 2017). To insert counterfeit drugs into the supply chain, drug counterfeiting groups dupe wholesalers into purchasing products they claim to be direct from the drug manufacturer (Dahod, 2017). The substandard drugs move along the supply chain as wholesalers then sell the product to pharmacies and hospitals, inevitably reaching patients (Dahod, 2017).

Lawmakers and health experts are working together to enact standards and regulations to increase drug integrity and promote full product traceability throughout the pharmaceutical supply chain. In fact, over 50 countries have introduced legislation designed to increase traceability and reliability of

pharmaceuticals from the manufacturing beginning of the supply chain, through to the patients (Packaging Europe, 2018). Two key laws put into effect are the EUFMD and DSCSA.

The European Union's Falsified Medicines Directive (EUFMD) went into effect in January 2013, outlining a set of requirements for members of the pharmaceutical supply chain to ensure drug integrity and patient safety (European Commission, n.d.). The three areas of requirements are serialization, verification, and compliance report (TraceLink, n.d.). EUFMD serialization requirements mandate that specific object and product identifiers be present on manufacturer's packaging (TraceLink, n.d.). Verification must be conducted at more than one stop along the supply chain therefore, serialization must be applied at the "saleable-unit level" of packaging (TraceLink, n.d.). The third piece to the EUFMD is the compliance reporting, for which manufacturers must report all serialization and identification information to the European Medicines Verification System (EMVS), the EU's database system used for tracking and authorizing legal pharmaceutical drugs (TraceLink, n.d.; EMVO, n.d.).

The U.S. was not far behind the EU in enacting their own regulation, the Drug Quality and Security Act, in November 2013 (U.S. FDA, 2019). Lastly in 2015, to specifically address management of the pharmaceutical supply chain, the Drug Quality and Security Act was improved to include Title II: Drug Supply Chain Security Act (DSCSA) (U.S. FDA, 2019). Requirements outlined in the DSCSA include the following: wholesalers and 3PLs must report their license to the FDA on an annual basis; all organizations within the pharmaceutical supply chain have 24 hours to report the identification of any "illegitimate" products (U.S. FDA, 2019). Unlike the EUFMD, the U.S. DSCSA has a multi-phased implementation approach with deadlines still in the future (U.S. FDA, 2015).

Initial requirements for product traceability were introduced through the DSCSA in 2015 and only applied to the "lot-level" product packaging (U.S. FDA, 2015). The manufacturing definition of "a lot" can be understood as the "defined quantity of a thing used as a unit of inventory, output, sales, sampling, or transportation… A lot is ordered, sold, released or delivered in its entirety" (Business Dictionary, n.d.). Given this definition and an understanding of the DSCSA requirements, one can infer that product traceability is currently only required in bulk format. The next phase of DSCSA requirements is scheduled to go live in 2023, and will require manufacturers to trace products at the individual package-level (U.S. FDA, 2015). In order to achieve this, the 2023 installment of the DSCSA will also require product traceability through an "electronic, interoperable system to trace products at the package-level" (U.S. FDA, 2015). This requirement shines a spotlight of opportunity for connecting the pharmaceutical supply chain to the internet of things.

4 The Pharmaceutical Supply Chain and IoT

Effective anti-counterfeit measures require system integration and connection throughout the pharmaceutical supply chain (Packaging Europe, 2018). Included in the integration should be "network, enterprise, site-level, line/warehouse, and device level systems" (Packaging Europe, 2018). Integrated product identification and traceability can enable members of the pharmaceutical supply chain and health organizations to quickly determine if the source of adverse patient reactions to medicines (Rut, 2018). Other benefits to data integration include the ability to pinpoint specific product lots which need to be recalled (rather than recalling dozens of lots to avoid overlooking bad product), the ability to quickly identify counterfeit or substandard drugs, and the trending of data to track possible adverse patient reactions to medicine (Rut, 2018). While these improvements to the pharmaceutical supply chain are undoubtedly necessary, there are challenges to overcome.

One challenge for wholesalers and manufacturers comes in the form of warehouse and inventory management (Pharma Logistics Editor, 2019). With the EUFMD and DSCSA requirements, warehouse

operational processes face the threat of interruption and inefficiency (Pharma Logistics Editor, 2019). Traditional warehouse operations are conducted manually, using verbal/teleconference communication to verify product upon receipt, and recording activities on paper (Pharma Logistics Editor, 2019). The product identification and traceability regulations require that all products returned to a wholesaler or manufacturer undergo a one hundred percent inspection to verify its integrity (Pharma Logistics Editor, 2019). Experts warn that warehouse operations may become overburdened and more expensive if automated systems aren't put in place to help organizations comply with product verification regulations (Pharma Logistics Editor, 2019).

Understanding the challenges, Fiona Ehret-Kayser of MarkLogic Blogs, encourages integration and believes that integrating systems to provide unfragmented, end-to-end visibility throughout the supply chain will lead to more efficient and more accurate manufacturing production operations (n.d.). She describes a lack of integrated data as a "barrier to sharing" preventing broader data analysis (Ehret-Kayser, n.d.). An additional benefit of end-to-end visibility is the natural reduction in the risk of counterfeits, promoting the integrity of drugs (Ehret-Kayser, n.d.).

In order to realize the benefits of end-to-end visibility and comply with regulatory requirements, pharmaceutical supply chain organizations have been working to expand their assets into the internet of things. There are several steps involved in the selection of a technology solution (Saboo, Chourey, & Suranglikar, 2017). Figure 2 below suggests a roadmap for organizations to prepare for and select the right IoT solution for their business needs (Saboo, Chourey, & Suranglikar, 2017).

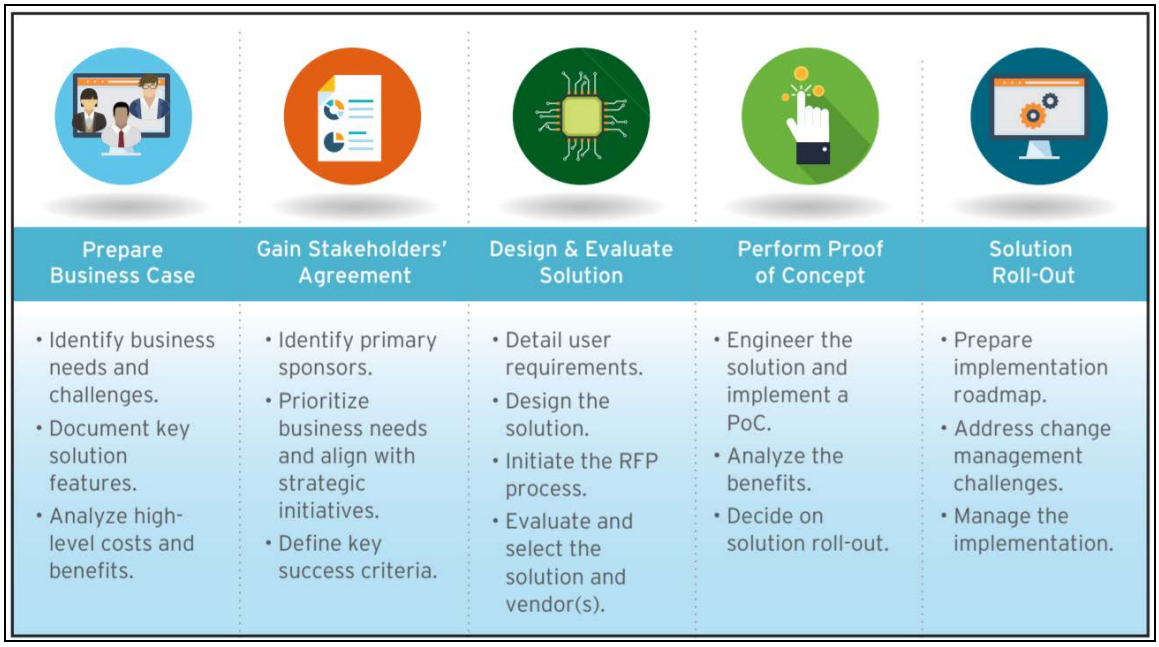

Figure 2: Selecting the IoT solution for the business needs (Saboo, Chourey, & Suranglikar, 2017)

In preparing for the DSCSA requirements, TraceLink conducted a survey among pharmaceutical organizations in 2016 asking for feedback regarding their preparation and implementation of serialization and verification technology solutions. The survey revealed that financial burden was one of the primary topics concerning organizations preparing to comply with the DSCSA requirements (TraceLink Insights, 2016). In a study conducted by The Pew Charitable Trusts, it was learned that the

average total cost of implementing serialization and verification technology solutions for a medium-sized company could be as much as $36 million (Booz, Allen, Hamilton, 2014). Small wholesale organizations' costs ranged from $44,000 – $81,000 (Booz, Allen, Hamilton, 2014).

Making necessary investments and selecting the right serialization and verification solutions has been so difficult for organizations across the supply chain, some regulations have been delayed. The original deadline for manufacturers to comply with the requirements of the DSCSA was November 2019 (Johnson, 2017). Upon deadline arrival, the FDA evaluated the status of manufacturer compliance and determined that a one-year extension was necessary to grant organizations further time to implement systems necessary to comply (Neil, 2017). Although this extension was offered to manufacturing organizations, deadlines for wholesalers, repackagers, pharmacies, and similar companies remained the same (Neil, 2017).

The pharmaceutical supply chain has continued its march towards the goal of integration and interoperability to achieve full serialization and verification compliance per the final DSCSA deadline in 2023. GS1 Healthcare US has conducted readiness surveys in 2017, 2018, and 2019 to gauge the pharmaceutical supply chain's preparedness for DSCSA (GS1, 2019). Their survey has evaluated the percent of packaging being scanned via barcode for verification at the three big wholesale companies, AmerisourceBergen, McKesson, and Cardinal Health (GS1, 2019).

Figure 3: Progress made by the "big three" from 2017 to 2019 (GS1, 2019)

Some experts believe the pharmaceutical supply chain can benefit from the internet of things in ways beyond serialization and verification. One example is the adoption of machinery and equipment capable of automating preventive/predictive maintenance requirements (Nichols, 2019). The ability to proactively maintain costly equipment and machinery will reduce the risk of substandard drug production, packaging, and distribution (Nichols, 2019). One pharmaceutical company lost $20 million of drug products due to a failed dehumidifying pump in their production facility (Digital Health, 2018). Now the company has implemented IoT-integrated sensors which monitor the area's humidity, raising alarms if necessary (e.g., in response to a failed pump), which gives the company the chance to pre-

emptively save millions of dollars (Digital Health, 2018). Cohero Health has brought IoT directly to patients by developing an inhaler that monitors pulmonary function and alert patients if their conditions worsen (Digital Health, 2018). This type of technology could be used to track patients' conditions, and alert healthcare organizations should a patient's condition indicate signs of substandard drugs.

The digital network platform and associated cloud-based Software as a Service (SaaS) products offered by TraceLink provide organizations with a web and mobile-based system that provides real-time information sharing capabilities (Southey, 2017). In addition to information sharing, TraceLink's SaaS provides manufacturers with the necessary software tools to generate, record, and verify product serialization, and then report those serial numbers to government agencies and other organizations throughout the supply chain (TraceLink Solutions, n.d.).

TraceLink has also made warehouse management part of the pharmaceutical industry's internet of things by offering the Smart Inventory Tracker (SIT) mobile application (TraceLink Applications, n.d.). In working with the SIT mobile application, warehouse workers are able to scan products in real-time while they are handling it. The SIT application verifies and updates the status of serialized product across three platforms for an organization: the TraceLink SaaS database, the organization's Warehouse Management System (WMS), and the organization's Enterprise Resource Planning (ERP) system (TraceLink Applications, n.d.). This integration provides organizations with the tools they need to maintain and control their internal records, and share information with other organizations connecting to the TraceLink database, while complying with the verification and serialization regulations (TraceLink Applications, n.d.). Not only has TraceLink supported the pharmaceutical supply chain on its journey to achieve regulatory compliance and end-to-end visibility, in April 2020 the company pledged $1 million to support for the current crisis facing the world of health and wellness (TraceLink, 2020).

On March 11, 2020 the World Health Organization (WHO) declared the outbreak of coronavirus disease 2019 (COVID-19) a "pandemic" (CDC, 2020; WHO, 2020). Experts from the CDC explain that COVID-19 is a new strain of coronavirus disease they believe developed from an initial human to animal interaction (2020). As cases of COVID-19 increased, doctors and researchers understood the continuous infection rate was due to person-to-person spread (CDC, 2020). Many healthy individuals, specifically under the age of sixty-five and with no preexisting health conditions, have been exposed to COVID-19 yet experience no symptoms (CDC, 2020). Despite that, many more have suffered from symptoms such as fever, chills, cough, and shortness of breath (CDC Symptoms, n.d.). As of May 1, 2020, the CDC's reported total number of COVID-19 cases in the United States were at 1,062,446; the reported total number of deaths were up to 62,406 (CDC Cases, 2020). Providing effective treatment to millions of cases has taken an unfathomable toll on the pharmaceutical and healthcare supply chain.

Closely monitoring the pharmaceutical supply chain for coronavirus-related impact, the FDA announced on February 27, 2020 that a drug manufacturer notified them of a product shortage (FDA, 2020). The drug manufacturer reported that their shortage was believed to be a direct result of COVID-19, which affected key-ingredient production by one of the manufacturer's suppliers (Hahn, 2020). In addition, the market demand for personal protective equipment such as gloves and masks has been insatiable as the need to treat coronavirus patients continues to increase (Hahn, 2020). Unlike with pharmaceutical drugs, the U.S. government has no law in place that requires manufacturers of products such as personal protective equipment to report shortages to the FDA (Hahn, 2020). At the time of Dr. Hahn's statement regarding the FDA's supply chain update, the Administration had not received any reports of personal protective equipment shortages (Hahn, 2020). The lack of regulation around personal protective equipment causes one to question if manufacturers had silently noted signs of shortages, not required to notify any agencies of the concern.

The next several weeks following Dr. Hahn's statement were wrought with hospitals and health professionals pleading for more personal protective equipment as the shortages became insurmountable (Chaib, 2020). In response, WHO released their recommendations for monitoring the global supply chain, asking that organizations and community members do their part to ensure effective distribution of personal protective equipment (WHO Guidance, 2020). Regardless of these efforts and many more in the industry to drastically increase production, some say this problem has been exposed in every pandemic-readiness analysis (Lopez, 2020). The inability to protect health care workers and ensure their health and safety directly correlates to the ability to successfully treat infected patients (Lopez, 2020). German Lopez of Vox suggests that global government collaboration identifying personal protective equipment supplies and fairly distributing them in a controlled manner could have lessened the shortages (2020). But in order to do this, not only do systems need to become more integrated, stream-lined, and capable of real-time augmentation, political obstacles would also need to be overcome such as where funding and control for any such program would come from and ultimately reside.

The Internet of Things offers real-time visibility to the integrated operations of people and equipment, environmental and societal effects of market demand, and the power to make immediate data-driven decisions within the pharmaceutical supply chain (Shugalo, 2019). The increased global use of end-to-end serialization and verification will help control how products enter the supply chain, and ensure fair and appropriate distribution (Saboo, Chourey, & Suranglikar, 2017). TraceLink CEO Shabbir Dahod explains that 95% of a manufacturer's supply chain is beyond their visibility (Pharma Logistics Editor, FutureLink, 2019). William King believes that as the internet of things evolves, it will provide increased connectivity throughout the world of healthcare (Hanhaa, 2020).

5 Conclusion

In order to realize the pharmaceutical supply chain of the future, organizations will need to adjust their way of thinking and adopt modern ways of conducting business. Integrating with IoT devices and digitizing manufacturing processes is the best path towards increasing production efficiency and achieving end-to-end visibility. As global society and government pressure on the pharmaceutical supply chain increases, especially in the wake of COVID-19 crises, organizational and agency commitments to an integrated supply chain network must increase. The IoT capabilities of tomorrow could empower individuals with the technological ability to register a supply of masks or gloves while in quarantine. An IoT application could provide manufacturing personnel with the ability to notify healthcare officials of their illness, generating increased visibility to production shortages. Connecting the pharmaceutical supply chain through the internet of things could save lives during the next global pandemic.

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