Leveraging Smart System Design to Collect and Analyze Factory Production Data

By

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Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in partial Fulfillment of the Requirements for the Degrees of

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and
Master of Science in Mechanical Engineering

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Abstract

Li & Fung deals with many factories that are very geographically dispersed. These facilities generally do not have the capital available to invest in new technologies and processes, and the extremely manual nature of garment fabrication is the standard as a result. As customers continue to demand quicker product turn-arounds and higher levels of customization, factories need to better understand their current process limitations in an effort to optimize their internal operations. Since most of these factories collect virtually no process data, managers have a hard time focusing on areas in which to improve. This project is approaching the question of “how can we use technology in a responsible and sustainable way to better understand our process?” from the perspective of a factory manager, who cannot necessarily invest in sophisticated software and hardware systems that other industries have adopted to monitor quality. As a result, this project focuses heavily on the user experience of both the operator (quality inspector) and the manager, as both need to be able to interact with the proposed data system easily and reliably.

The primary goal of this thesis is to detail the design and implementation of a data collection platform (built during internship) for use in low-tech garment factories that will:

- Enable the procurement of process data (specifically as it relates to quality) from operators in real-time.
- Allow factory management to easily view and analyze collected data.
- Employ an intuitive front-end user interface that allows operators to quickly and reliably collect data.

Since a substantial portion of this internship was spent designing, building, and testing this data collection interface, the thesis will reflect the nuances associated with building and implementing factory data systems in low-tech factories where human interaction is the primary driver of system adoption. The design and deployment of this system was ultimately successful and resulted in a robust prototype that continues to provide Li & Fung with insights into how to achieve their ultimate goal of connecting their factory network to a centralized data platform.

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I want to thank everyone who helped in the development of this thesis. It was truly a once-in-a-lifetime experience to move to Asia for 7 months both from a personal and professional perspective. My original goal in coming to MIT was to surround myself with and enhance my understanding of the world of technology. In the end, the most important lesson I learned is that technology is all about the people that use it. This thesis gave me the opportunity to engage with amazing individuals and witness firsthand how technology can be a universally understood language. Ultimately, this project is all about the operators – those individuals stitching, cutting, washing, and inspecting countless garments day in and day out. As technology becomes more and more accessible all over the world, I challenge factories to continue to strive to become healthier, safer, and more environmentally friendly places for those who rely on them in ways that are hard to imagine.

I want to thank…

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1. Introduction

1.1 Project Motivation
Li & Fung is a global supply chain manager that sources products to thousands of factories in its supplier network. Historically, Li & Fung has operated primarily in the garment industry, with its primary client base consisting of most of the western world’s largest clothing brands. As evidenced by a changing status quo in the retail sector (greater emphasis on ecommerce, insourcing, etc.), the industry in which Li & Fung operates is facing challenges from many sources. Li & Fung’s financial performance over the past decade is evidence of a harsh retail environment. The firm is facing challenges to its core business, and needs to adapt the way it interacts with its factory supply network in an effort to continue to incentivize customers to source with Li & Fung. In today’s increasingly global business environment, brands have a complex decision when it comes to sourcing. Traditionally, Li & Fung profited extensively from the fact that China was the low-cost labor solution to the West’s manufacturing needs, and they were extremely well connected with the local production network. As China becomes more economically advanced, this low-cost labor has shifted all over Southeast Asia and surrounding regions. Li & Fung has continued to operate and maintain a presence in most of Asia, but the reality is that their traditional “middle man” status is being challenged by changing industry dynamics. As a result of not being able to solely rely on connections and industry knowledge as a competitive advantage, Li & Fung is looking for ways to add value to its clients outside purely logistical means. Li & Fung is betting that technology and data-driven insights are the future of the sourcing agent’s advantage, and is making large investments in both of these areas. In theory, if Li & Fung is able to cooperatively make their existing factory base more sophisticated and more productive, they could offset some of the effects of rising labor costs.

This thesis aims to identify how inherently low-tech garment factories can leverage technology and data collection to become more productive. It also outlines how having basic production data

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1 (Morningstar Financials, 2018)
2 (Gopalan, 2017)
will help Li & Fung to establish an enhanced viewpoint into the world of its factories, and how this data platform will help provide value and insight to its customers.

1.2 Li & Fung

1.2.1 History of The Fung Group

To understand the historical context in which Li & Fung operates, it is important to consider how the firm has grown over time. Li & Fung was founded in Canton in 1906 by Mr. Fung Pak-liu and Mr. Li To-ming. They were one of the first companies financed solely by Chinese capital to engage directly in exporting from China. Its initial trading business was focused on porcelain, silk, bamboo, jade, ivory, handicrafts, and fireworks.\(^3\) Due to the geographical makeup of the Canton region, the water in its port was too shallow for large ocean-going ships. As a result, the Group had to establish a separate branch in Hong Kong, which had a much deeper port and allowed for ocean-based trade. The firm’s division in Hong Kong became its first separate branch, and handled the shipping of all of its goods.

Li & Fung was formally established in Hong Kong on December 28, 1937 as a limited company. In the following decades, Hong Kong established itself as a manufacturing hub built on exports of consumer products. Mainland China closed itself off from the rest of the world, and Hong Kong remained an international trading post. Li & Fung took advantage of this newfound economic engine, and began to export garments, toys, electronics and plastic flowers in addition to its original product lines. As the company continued to grow and expand its business, its financial performance boomed. When Li & Fung first listed on the Hong Kong Stock Exchange in 1973, the offering was oversubscribed 113 times.

In 1979, Mainland China re-opened itself to international trade. As a result, Hong Kong manufacturing activity largely relocated to the Pearl River Delta region in South China to take advantage of more competitive labor rates and workforce availability. This increased economic activity in South China catalyzed a period of growth in the region in the 1980’s, during which the region largely became more industrialized and its capabilities expanded. Li & Fung understood

\(^3\) (The Fung Group, 2018)
this growth well, and was able to successfully grow in the Pearl River Delta’s manufacturing ecosystem and leverage its institutional knowledge in its trading business. During this time, Li & Fung also established regional offices around the South China geography, which allowed it to quickly respond to customer demands and leverage a changing production ecosystem.

In 1985, Li & Fung established a separate retailing arm of its business. It created as a wholly-owned subsidiary of the Li & Fung Limited. The retailing arm primarily serviced two clients – Circle K and Toys“R”Us. This retailing operation was mainly built to work in the economies of Southeast Asia from their main office in Hong Kong. Five years later, Li & Fung was taken private in one of the first management buyouts in Hong Kong. This privatization of the firm resulted in a restructuring of the business into two core units – export sourcing and retailing.

In the 1990’s, Li & Fung began to expand its operations globally and looked to tap into sourcing capabilities outside of East Asia where it traditionally operated. They grew a presence in South Asia, the Caribbean, and the Middle East. This move was important for the Li & Fung that we know today; the group currently sources all over the world and taps into manufacturing networks nearly everywhere. During this period, Li & Fung also made some high-profile acquisitions in a directed effort to increase its customer base to Europe and North America. At this point, they had grown to service clients all over the world.

In 2012 the business created four separate business groups – Trading, Logistics, Distribution, and Retailing – under the Li & Fung Group umbrella to better distinguish their core competencies. This corporate structure lasted for about two years, before it was re-structured again. They spun off their wholesale distribution business for branded apparel, footwear, fashion accessories, and lifestyle products into a separately listed company called Global Brands Group (GBG). The trading and logistics business continued under Li & Fung Limited, while the retailing business continued under Fung Retailing Limited. These entities are the companies that currently comprise the current corporate structure of the Fung Group. As it stands today, the Fung Group hopes to continue to interact with Mainland China as the economy continues to grow. Figure 1 shows a current representation of the corporate structure of the Group as it exists today.
The Group's Trading and Logistics businesses are under Li & Fung Limited, which is the leading consumer goods design, development, sourcing, and logistics company for major retailers and brands around the world. With a growing network of over 15,000 suppliers in more than 40 countries, it specialises in responsibly managing sustainable supply chains of high-volume, time-sensitive goods. It also offers a customisable menu of logistics solutions, from warehousing, transport, repacking, and customs brokerage to freight forwarding, hubbing, consolidation and other value-added services.

Distribution

The Group's Distribution business for branded apparel and related products is operated by Global Brands Group Holding Limited. It designs, develops, markets and sells products across a diverse brand portfolio and creates new opportunities, product categories and market expansion for brands on a global scale.

Retailing

The Group's diverse Retailing businesses operate under Fung Retailing Limited, including the publicly-listed Convenience Retail Asia Limited and Trinity Limited, and the privately-held Branded Lifestyle Holdings Limited, Fung Kids (Holdings) Limited, Toys R Us (Asia) and Suhyang Networks.

**Figure 1** Current Organizational Structure of Fung Holdings

1.2.2 The Fung Academy

The Fung Academy is the primary research and development arm of Li & Fung. It is the area of the company in which the LGO interns have worked in the past, and sits separate from the core business of the rest of the organization. The Fung Academy is privately financed by the Fung family, and sits above all of the supporting business units. Figure 2 shows a simplistic view of the

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4 (Fung Group, 2018)
organizational structure of the Fung Academy and the Fung Manufacturing Excellence Program (FMEP), described in more detail in the next section.

The Fung Academy consists of the following functions:

- The Program for Management Development (PMD) – This function is aimed at identifying and training leadership talent for the Fung Group. They have an annual intake of PMD candidates, and rotate them throughout the organization.

- Corporate Capability Development – This function designs learning programs for leadership within the Fung Academy. Through initiatives like partnerships with top US-based universities, this group aims at continuous learning for management. The Fung Academy often brings in high-profile speakers, thought leaders, and professors to lecture its top leadership.

- Innovation & Experimentation – This group focuses on using prototyping new solutions for end customers in the context of technology. For example, they work with new fabrics and wearable electronics to develop interesting concepts that they can share with Li & Fung customers as part of the new product development process.

- Supply Chain Futures – This group focuses on increasing the capabilities within the Li & Fung supply chain and production network. Objectives like digitizing factory data, increasing supplier sustainability, and introducing new factory technologies to suppliers all fall under this function.

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5 (Fung Academy, 2018)
LGO interns who have worked with Li & Fung have worked in the Supply Chain Futures group under the leadership of its Director, Ms. Pamela Mar. This group is the most directly connected to the operations of the core business, as its primary goal is to interact with factories and suppliers to increase their capabilities in a mutually beneficial way to them and Li & Fung. During this internship, the Supply Chain Futures group was about seven people (including the LGO interns) and had a variety of initiatives on which it was working. For example, they were focusing heavily on integrating energy sensors into factories to monitor energy usage and propose areas in which to cut back on power consumption.

1.2.3 Fung Manufacturing Excellence Program (FMEP)

The Fung Manufacturing Excellence Program (FMEP) is a group within the Fung Academy that is focused mainly on providing operational consulting to Li & Fung’s installed factory base. At the start of this internship, they sat as a distinct sub-group within the Fung Academy. Around the halfway point in the internship, they transitioned into the core business and out of the Fung Academy umbrella. However, they are critically important to this thesis because they are a part of the organization that directly interfaces with factories on improvement and lean transformation projects. FMEP consists of a few individuals that have backgrounds in lean manufacturing. They work with factories in the Li & Fung production network to make them more operationally efficient. They also work on transformation projects such as trying to reduce the temperature of factories to make the working conditions better. The FMEP is strongly relevant to this thesis because it is the team that was most closely worked with during the factory visits. FMEP members had multiple connections to factory managers in China and India, where most of the testing took place during this internship.

1.3 Industry Challenges

1.3.1 Changing Manufacturing Landscape

In the past decade, Li & Fung has seen drastic changes in their operating model due to the changes in wages and economic status of its main hubs. One trend that has affected Li & Fung’s business is the increased labor costs in China. Since Li & Fung’s clients rely on it to provide the most cost competitive labor and manufacturing practices, they have had to adapt their factory base to areas
with lower cost labor. In terms of garment production, labor typically accounts for between 15% and 22% of the total cost of a garment\(^6\). Figure 3 shows how wages of Chinese manufacturing employees has risen in the past ten years.

![China Average Yearly Wages in Manufacturing](chart)

**Figure 3** Rising Salaries in Chinese Factories Put Pressure on Li & Fung’s Operating Model

China has accounted for a large portion of Li & Fung’s installed factory base over the years. As it stands today, they have large operating units in India, Bangladesh, Indonesia, Vietnam, Thailand, as well as many other countries in Southeast Asia. However, the trend that we see in China of increasing labor wages has also been seen across other developing economies. The decision of where to source and how much to invest in the suppliers given the transient economic conditions has been a challenge for Li & Fung and brands who rely on cheap labor.

### 1.3.2 Changing Consumption Patterns

Consumers are changing the way that they demand clothing. One apparent trend that has emerged in the past couple of years is the concept of “fast fashion.” Fast fashion is a colloquial term that connotes the industry’s shift to higher mix, lower volume orders and quicker product turnarounds\(^7\). This is driven by consumer trends towards higher levels of customization in their purchasing

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\(^6\) (Holmes, 2010)  
\(^7\) (Investopedia, 2018)
habits. Also, it is driven by brands feeling pressure to offer more products with a greater emphasis on style, which forces the design and production schedules of garments to be shorter. In essence, the time between when garments make their debut on the runway to when they appear on the shelves of stores is decreasing. Companies like Zara have established strong positions in this “fast fashion” market, as they have consolidated their design cycle to a matter of weeks, and supply products to storefronts in a fraction of the time of their competitors. This means that as the industry demands high product differentiation, textile mills will need to further optimize their cost and speed of production. Doing so will require a higher degree of operational excellence in garment factories. Li & Fung will need a way to be able to evaluate its supplier network based on productivity and ability to produce smaller orders in a large degree of styles. To do this, they will need to collect productivity data on factories in its production base, and allocate orders to factories that exhibit the right combination of proximity to the customer and ability to produce the orders on time. In their current state, factories will have difficulty collecting and analyzing various sources of data that can be used to improve operations to this effect. Any data collection processes that exist in some capacity in garment factories are laborious and prone to collection error.

### 1.3.3 Regulatory Changes

In the past decade, we have seen an increasing emphasis placed on safe and sustainable factories. As regulations change in places like China, it becomes increasingly necessary for factories to think about compliance in different ways. For one, looking at the recent crackdown of the Chinese government on polluting factories in which thousands were closed in the name of improving air quality, managers and owners are beginning to accept the fact that the need for more operationally advanced factories is becoming increasingly necessary. As it relates to productivity and enhanced technological capabilities, Li & Fung is very interested in better quantifying which of its factories are the “safest” from an environmental perspective. This means that establishing a data platform through which sensory data (energy usage, waste water toxicity, etc.) is of interest to both factory managers and Li & Fung, since doing so would allow better quantification of compliance and serve as a baseline for improving the sustainability and waste levels of their component factories. As

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8 (Editorial, 2016)
9 (Schmitz, 2017)
regulations get more apparent at the factory level, Li & Fung needs a way to be able to better evaluate the compliance risk of its supplier network.

1.3.4. Organizational Challenges

It is important to discuss challenges that exist for Li & Fung as a result of its organizational structure. Since it functions as a true “middle man” between customers and factories, Li & Fung does not directly own any of its production resources. Its supplier base is made up of a network of factories that spans multiple continents, almost all of which are owned by third parties. Since Li & Fung does not own these factories, they have an added challenge of trying to implement new solutions and technologies since they cannot force factories into anything. Li & Fung contracts a certain percentage of a given factory’s capacity, and so they have a very high amount of leverage in most of their facilities. This makes it easier to get factories to adopt their operating agenda and make significant changes if necessary. However, at the end of the day, it is up to individual factory managers to implement changes and improve their processes, and Li & Fung often does not have the final say. In terms of this thesis, it became apparent that Li & Fung often struggles with getting factory managers to see the value in new technology and capabilities. As a result, Li & Fung spends significant resources on educating factory managers and selling them new methods and technologies, often at a discount. Li & Fung will often subsidize technology and operational improvement projects to suppliers that it knows will benefit from these projects. In addition, since many of Li & Fung’s factories have effectively no money to re-invest in upgraded processes and equipment, they are looking into a financial mechanism that will provide factories with a line of capital that they can use to invest in new technologies at extremely low interest rates.

Another source of challenge for Li & Fung is the makeup of the different business units. As described in previous sections, Li & Fung consists of many discrete business units and has changed to meet customer demand over time. As the firm has added new customers over the years, it has created new divisions within the company to handle the business of those customers. For years, Li & Fung has seen this as a positive; they felt as if they had an unparalleled ability to meet customer demands and tailor solutions to their big clients. While there are some advantages in this model, it is clear that most of the organization is very closed off to other parts of the business. For instance, business units do not have a habit of centralizing data related to suppliers, factory conditions, contracts, etc. that may be useful to other parts of the organization. When
implementing organizational change projects such as factory transformations, it is extremely
difficult to identify important factories to the Li & Fung organization because the company
functions very individually between business units.

1.3.5 Explanation of Industry Power Dynamics

In understanding why factories have not invested more in their capabilities, it is important to
discuss the sourcing and procurement process for large brands such as Gap and Macy’s. There are
typically four main “players” in the supply chain for garments. They are brands, sourcing agents,
factories, and material suppliers\(^\text{10}\). Brands are the end customers of the garments, and will pass on
product requirements to the sourcing agent. In general, brands will design their clothes in-house
about part of the time, with a significant portion of the work being outsourced. Sourcing agents,
such as Li & Fung, take customers’ orders and coordinate the supply chain and production plan
for the order. Sourcing agents often do not own any factories directly, but rather contract to a
global network of production facilities to do the fabrication of the garments. This is because in
the current state of the industry, the production network is constantly shifting geographical
locations to chase the lowest labor costs. Sourcing agents play the “middle man” role and sit
between the brands and the production and raw material suppliers. They charge a markup for their
high leverage in factory contract pricing and specialized sourcing and logistical expertise.
Factories are the producers of the garments, and are typically located in Southeast Asian countries
where labor rates have historically been low. In general, these factories are relatively small family-
owned businesses, and make extremely low profit margins on the garments that they produce. This
affects their ability to improve fabrication processes and introduce quality management,
sustainable solutions, and automation into the factories. At the end of the supply base is the raw
material supplier. This is typically a firm that operates similarly to the factory in terms of
management and profit profile. These raw material suppliers have extremely little room to grow
their capabilities, and have to streamline costs in any way possible.

Thinking back to the sourcing agent, it becomes apparent that they have tremendous power over
the factories and raw material suppliers. Since companies like Li & Fung have the network and

\(^\text{10}\) (Stauffer, 2017)
connections to constantly chase their most cost-effective suppliers, they do not typically assist them in creating better or more sustainable processes. From a marketing standpoint, big brands are somewhat insulated from bad press associated with poor labor and environmental factors since they do not typically own any of their production network (although some companies do). Since these garments are produced in such large quantities, cutting raw material costs is essential when sourcing agents make their decisions. These pressures get passed onto the suppliers themselves, who are incentivized primarily on their ability to supply high-quality low-cost materials to the factories for production. Framing this in the context of externalities, we can see that the pressures put on these low-tier suppliers coupled with often lax environmental regulations in the countries where these suppliers operate leads to wasteful enterprises that put capability investment low on their priority list.

1.4 Questions Addressed

The primary hypothesis being tested in this thesis is that by focusing on user design, a low-cost and easily implementable data collection system can be developed that provides valuable data to factories and to Li & Fung. The FMEP team suggested this area of work based on their observations in looking for inexpensive ways to provide factories with high-value tools to help improve their operations. At the start of this project, two major questions were outstanding.

- What does the ideal data collection interface look like? What user design characteristics will lead to its success?
- What data do factories and Li & Fung need to collect to drive operational improvement?

Throughout this thesis, these questions will be addressed in detail. The basis for the solution resided in a deep understanding of the operator’s needs and tendencies, which were studied by first-hand observation in the factories. Ultimately, the conclusion was reached that the best way to collect reliable process data is to design a system that users find intuitive, enjoyable, and informative.
2. Literature Review

2.1 Human-Centered Design (HCD) Process

This project focuses heavily on developing a solution for operators that works well in the context of their current process. In general design terms, it was extremely important to consider the input of the end user of the system when designing and optimizing the user interface for the task at hand. Although simple in philosophy, human-centered design (HCD) is a powerful tool when used to create intimate solutions to problems with many stakeholders. HCD is also known popularly as “design thinking.” It is known as a design and management framework that develops solutions to problems by involving the end user’s perspective in every step of the design and problem solving process. This framework was first popularized by work done at the Stanford Design School and consulting firm IDEO. Figure 4 depicts a popularized version of the different components of HCD.

![Figure 4: Pictorial representation of the Design Thinking Framework used at IDEO](source: STANFORD D.SCHOOL & IDEO)

The HCD process consists of frequent interactions with the main users of a system, rather than an isolated design process in which designers create a solution and rely on users solely for end testing. In both hardware and software development, this has become a new standard way of creating products. More generally speaking, organizations of all types are beginning to leverage the concept of heavy stakeholder interaction when developing all sorts of products and services. From

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11 (International Organization for Standardization, n.d.)
hospitals to insurance companies, HCD has played a role in the design process moreso now than ever. Benefits of including heavy interaction with the user include the following:\textsuperscript{12}:

- Increasing the productivity of the end user due to the fact that the solution was co-developed to tailor their needs.
- Reduction of training and support costs because the system was intuitively designed by the end user.
- Improved user experience, and hence less frustration and lower risk of improper use.
- Reduction of stress and discomfort associated with physical products (ergonomics).
- Using intimate consumer knowledge as a competitive advantage for corporations.

A recent article by Dave Thomsen, a former IDEO employee, sums it up nicely. He identifies a few key ways to employ HCD in the context of product design. They are as follows:

- Ask the Right Questions: in many cases, the designer is not focusing on asking the right questions of the end users of the product. Instead of asking questions that relate to specific attributes of the product (“how large should we make this laptop?”), the designer should ask more generally about the experience (“how will the user interact with / store / carry the laptop?”). It is important to put the design problem into the context of the user experience rather than focus on individual product attributes without user feedback.

- Get out from Behind Your Desk: engage early and often with the users of a system. Do not attempt to extrapolate what design characteristics are important; this comes best from observing and listening to the end user. On-site testing is extremely important, and monitoring stakeholders in their end environment is critical for understanding all aspects of the system.

- Make User Feedback Routine: be sure to include user feedback at every stage of the design process. When there are significant time pressures to get product shipped, do not let this affect the ability to engage meaningfully with the end user and have a conversation to determine how the system can be improved.

- Think of Design as a Team Sport: leverage the collective abilities of everyone on the design team. Rather than building teams that are very similar in skillsets, make sure that you have

\textsuperscript{12} (Buchanan, 2001)
a diverse pool of talent across the team members. Treat all ideas as important ideas that belong to the collective team instead of a single individual.

- Build Minimum Viable Prototypes: Minimum Viable Prototypes (MVPs) were popularized by Eric Reis in his book The Lean Startup. Essentially, this term promotes the idea that it is important to iterate quickly and early. When trying to get user feedback, it is critical to design a prototype that they can interact with that has the desired functionality that the designer needs to test. Rather than spending significant time and resources creating a final product and testing it with users at the end, it is important to prototype early in the design process as a way to observe users interacting with various levels of the product.

At many levels in large organizations, HCD is becoming a more widely adopted industry standard. Many companies have created design groups that have tried to apply these learnings to products and services to engage customers in new ways. A few examples are IBM, MassMutual, and Fidelity. These firms traditionally did not employ HCD processes in their service design, but have been able to successfully tap into new markets by concentrating more on the user experience.

2.2 Factory Data and Technology Adoption

The idea that process data is valuable to collect in the manufacturing context is not new. In recent years, firms from all over the world have begun to incorporate automated machinery, sensors, and process software in an effort to make their operations more productive. In garment factories, technology has been adopted slower than in most industries due to the lack of incentives for managers to invest in capital equipment and technology given their current profit structure. This section will discuss two areas in which previous work has been done in factories: Internet of Things (IoT) and new production equipment.

2.2.1 Internet of Things (IoT)

The Internet of Things (IoT) refers to the connection of devices to the Internet. These can range from complex sensors to simple pushbuttons. Anything with an “on/off” switch can be part of the

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13 (Digital Surgeons, 2017)
14 (Morgan, 2015)
IoT, as long as it is connected to a central platform through which data can be accessed. The IoT has many applications, including both consumer and enterprise use cases. On the consumer side, many of the applications are focused on “smart home” uses, such as a refrigerator that will automatically re-order food when it gets low on stock. In the enterprise setting, applications often exist in the production / operations area of businesses, as IoT allows for unique insight into the supply chain and manufacturing process. According to the Industry 4.0 framework, some use-cases of IoT in manufacturing are as follows:\(^5\):

- Production Asset Management and Maintenance: enhanced predictive maintenance, preventing breakdowns, etc.
- Field Service: more intelligent scheduling of services, ware, etc.

As companies begin to use integrated sensors in more aspects of their core business functionality, they will begin to piece together a more comprehensive picture of how product is created and maintained from a data perspective. This will enable companies to derive process insights like they have not been able to in the past. In fact, it has been estimated that 67% of companies in the manufacturing sector have an ongoing smart factory initiative\(^6\). This project focuses heavily on IoT technology, both from the hardware and the data management perspective.

2.2.2. Production Technology Adoption

Garment factories are inherently low-tech places. Managers often do not have the capital available to invest in new processes or technologies. As a result, there are low levels of automation and other production enhancements because of the lack of capability in these factories. According to Zach Stauber’s LGO thesis, there are a few critical technologies that factories have begun to adopt\(^7\):

\(^{15}\) (Scoop, 2017)  
\(^{16}\) (The Atlantic, 2017)  
\(^{17}\) (Stauber, 2017)
• Electronic sewing machines: sewing machines have not changed much over the past 50 years. In general, they have added more basic assistance with non-value-added tasks such as thread trimming. These sewing machines are not automated, but have made incremental improvements on the sewing machines from 50 years ago.

• Specialized sewing machines: these are very similar to electronic sewing machines, but have additional functionality built in to help accomplish a specific task. For example, this may include automating the collar stitching process, the pocket stitching process, etc. This specialization of task-based sewing machines is relatively new, and represents a slight shift to operational improvements.

• Whole-garment knitting machines: knitting requires a different process than woven fabric. This type of machine assists in making this process more productive, in that it produces a single knit garment in one piece with no seams.

• Robotic arms: devices that include high levels of automation and robotics are very new for garment factories. Since fabric is inherently very flexible, it is not easy to fixture. This makes automating the stitching process very difficult. There are some firms that are focusing on producing automated equipment for textile production, but the rate of adoption in the factory context is very low.

• Conveyor Systems: these production systems aim at enabling factories to produce garments in a linear flow fashion, with a single garment traveling from operation to operation in sequence, as opposed to the current batch method. This will theoretically lead to less inventory on the floor.

• Real-Time Digital Data Capture Systems: these systems aim at enabling the collection of real-time information on production. This will enable enhanced viewpoints into line balancing, efficiency, and quality. RFID technology is a specific example of a system that can enable production data to be collected on individual pieces of clothing as they travel down the production line.

The above examples of factory equipment are meant to serve as context for the types of “state of the art” technology in the textile manufacturing space. Comparing these technologies to those of many more sophisticated plants, such as in the aerospace & defense sector, it is noteworthy to examine how drastically different the state of the art is across industries. While it is true that many
plants are much more technologically sophisticated than garment factories, many of the core challenges behind technology adoption and process re-organization are inherently similar.

This project focuses on a technology that falls in the “Real-Time Digital Data Capture System” category, defined above. The goal is to enable factories to collect data on the production process, to better assess (1) how many garments are produced during a given timeframe, (2) what percentage of garments are defective, (3) what the sources of the defects are, and (4) how long it takes, on average, to produce a single garment. These goals can be accomplished through a variety of methods. As discussed above, RFID technology is one potential candidate. Equipping inspectors with tablets, pushbuttons, etc. is another possibility. Following sections of this report will focus on the methods used to procure production data. Many factories around the world have developed robust ways to collect process and quality data. However, capturing this data has not become a widely-adopted reality in the garment industry. Efforts to better collect and interpret process data are relatively new to the garment industry, and this thesis aims at developing highly contextual solutions for this process.
3. Design Approach

3.1 Design Goals and Deliverables

This thesis involves significant amounts of user testing and design iteration. At the beginning of the engagement with Li & Fung, there was a collective understanding between the intern, Li & Fung, and factory managers about what the end product should enable from the standpoint of data collection and analysis. The primary goal of this thesis is to design and deploy a data collection platform for use in low-tech garment factories that will:

- Enable the procurement of process data (specifically as it relates to quality, cycle time, etc.) from operators in real-time.
- Allow factory management to easily view and analyze collected data.
- Employ an intuitive front-end user interface that allows operators to quickly and reliably collect data, with minimal risk of system misuse.

These goals evolved from the fact that there is no robust way in many garment factories to quantify simple production metrics, such as “how many non-defective garments did Factory ABC produce today?” Li & Fung developed the concept of equipping an operator working as an end-of-line inspector with a tablet-based application, through which they could specify number of non-defective garments inspected, defective garments inspected, and the type of defects that caused a garment to fail inspection. This idea was developed between managers in the company, and they needed assistance turning this high-level concept into a usable product that operators could interact with on the production floor. At the start of this thesis project, Li & Fung had developed an app that was based on an Android tablet that contained some of the above functionality. It was apparent that this application, while functionally useful, would be too difficult for operators to interact with. It required them to navigate complicated menus, manually type defect names, etc. Moreover, it would be difficult to train operators on and would leave the company at risk of acting on incorrect data. This project quickly became an effort to build these tools in-house, and include the user of the system in the design process such that the most optimized system would be developed.

The hardware deliverables that were created as a result of the above goals are as follows:

- User-tested prototype of front-end data collection system (using push buttons, tablet, etc.)
An essential component to creating a reliable system for use in factories will be to understand how users collect data. A major project goal will be to study user habits and recommend the most reliable system.

- Prototype of the back-end data analysis tool that managers will use to view and understand the process data.
- Requirements document that Li & Fung can use to clearly communicate exactly what external vendors need to develop to scale project into an enterprise-grade solution.
- Pilot deployment of the data collection system with documented results in a factory in two different factories.

3.2 System Benefits and Current State

This data collection system is of importance to factory managers, as it will allow for enhanced process clarity and in turn will be essential in diagnosing quality issues in the manufacturing process. Throughout early interactions with operators during visits to plants in China and India, it became clear that user experience is essential in designing this data collection platform. Currently in the most sophisticated portfolio factories, quality inspectors are given instructions to record defect information on a piece of paper (tally marks). In most cases, operators completely neglect this task as it adds time to the inspection process. In nearly all cases, even if the data was recorded, it was not done so in real time, and the data was not reliable as a result. Hence, the primary goal of this 6-month internship as it relates to the data collection platform is to explore the data collection process from the perspective of the operator, and design a system that properly incentivizes the user to interact with the system in the intended manner.

Li & Fung deals with many factories that are very geographically dispersed. These facilities generally do not have the capital available to invest in new technologies and processes, and the extremely manual nature of garment fabrication is the standard as a result. As customers continue to demand quicker product turn-arounds and higher levels of customization, factories need to better understand their current process limitations in an effort to optimize their internal operations. Since most of these factories collect virtually no process data, managers have a hard time focusing on areas in which to improve. This project is approaching the question of “how can we use technology in a responsible and sustainable way to better understand our process?” from the perspective of a
factory manager, who cannot necessarily invest in sophisticated software and hardware systems that other industries have adopted to monitor quality. As a result, this project focuses heavily on the user experience of both the operator (quality inspector) and the manager, as both need to be able to interact with the system easily and reliably.

3.3 Design Approach Given Internship Timeline

The first step in understanding the context in which this project will occur was to visit actual Li & Fung portfolio factories in different areas. Visits were made to multiple factories in China and India which provided a good cross-section into the different personalities of the factory managers and operators that run these facilities. In addition, these visits provided a framework to understand what the current-state of technology adoption is in these factories, and how data plays a limited role in everyday operations.

As mentioned above, the primary concern with this data collection system is the usability and design of the front-end experience. The first portion of this internship was spent understanding factories, brainstorming system architecture, prototyping hardware and software, and ensuring functionality with a back-end data collection platform. The later portion of this internship focused on testing a variety of hardware and software solutions with operators to understand the limitations of their ability to reliably collect data and iterate on previous ideas to find the most optimal solution. It also focused on the factory managers, who gave extensive input into what data should be collected and how it should be displayed and analyzed. Finally, time was spent with these managers to collaboratively use the collected data to made real-time operational improvements to the factory.

Since testing and quick iterations are key to converging on the most optimal data collection methods, both the front-end and back-end components to this system were prototyped as part of this project. Although this took some time in the first half of the internship, it allowed for better understand of the inner-workings of the system and to quickly iterate and adapt to test results when on-site in the second half of the internship.
3.4 Understanding How a Garment Factory Works

Garment factories, also known as “cut and sew” shops, are very low-tech places. This section will describe a bit about what these factories look like on the inside, through first-hand observation and research into Li & Fung’s factory base. During the course of this thesis, approximately 10 factories were visited in China and 5 factories were visited in India to get a sense of what the operating environments of these factories are. Of the factories that were visited, the majority were simple “cut and sew” factories.

3.4.1 Factory Operations

Upon entering one of these facilities, one of the first things to notice is that the tooling involved in the production process largely consists of sewing machines, irons, cutting tools, etc. While all factories vary in their level of process organization, most could benefit from an enhanced linear flow to the production process. The fabrication process for many pieces of clothing is as follows:

1. Cutting: Large rolls of material are laid out on a cutting table. These sheets are laid approximately 30 thick, so that one cut produces 30 of a piece. The operator then sketches the cut path according to a template with a piece of chalk, guessing at the most optimal arrangement of garment outlines on the sheets of fabric. The operator takes a band-saw type gadget and cuts the pattern manually.

2. Stitching operations: Once the patterns are cut, they undergo a series of stitching operations to construct the garment. This is largely done at the sewing machines. Each factory has a different way to represent “standard work,” and have a different division of labor to produce a finished garment.

3. Finishing operations: Once a garment is nearly finished, things like buttons on jeans and shirts are applied. This also includes elements such as fading and cuts for style. This is largely done manually at a “workstation” by an operator. Even in high-volume facilities, such as those that produce jeans, activities like producing stylistic fading and ripping on the garments is done by hand. Figure 5 shows two operators using dremel tools to cut garments to get “ripped” styling elements.

4. Inspection: An operator inspects a finished garment, and decides if it passes or fails. A passing garment gets shipped, and a failing garment needs to either be reworked or
scrapped. These inspections sometimes occur multiple times throughout the production process.

![Figure 5 Operators using hand tools to get stylistic rips on jeans for an order](image)

Although these steps may seem fairly logically organized, many of the facilities do not employ lean manufacturing principles at all in the factories. There is little emphasis on establishing a logical production flow, inventory is piled up all over the factory, workers are often confused on which jobs they are doing, and there is a significant amount of scrap and waste in the process. Figure 6 depicts one of Li & Fung’s large contract manufacturers.
3.4.2 Factory Working Conditions

In terms of the conditions of the factories that we visited, it should be noted that many of the factories are considered to be fairly sophisticated among the supplier base that Li & Fung contracts to, and hence working conditions were on the good end of the spectrum. Nevertheless, the temperatures were upwards of over 100F in many of the factories we visited, with little emphasis placed on providing workers with a comfortable work environment. Given the low-cost nature of the operation, it appears as if this is the standard for the garment industry and there is little leverage that factory managers have over the situation. It is important to note that in the case of many of the factories that we were able to visit, there were fans and other cooling elements; but the design of the buildings and the layout prevented them from having much of a significant cooling effect.
3.4.3 Endline Inspection Process

This project focuses significantly on the “endline inspection” part of the garment production process. At this point in the process, operators check to determine if a garment is ready to be shipped (“pass”) or needs to be re-worked / scrapped (“fail”). In today’s garment factories, this process is fairly unsophisticated. As garments finish being fabricated, they are transported to an endline inspection table. The operator will perform a check based on the type of garment that is being inspected, looking for things like stains, stitching defects, tears, etc. At this point in the process, the operator will throw the garment into the “good” pile if it passes inspection, and into the “bad” pile if it fails inspection. Figure 7 shows a picture of an endline inspection table in one of the factories visited during this internship.

![Endline inspection table in a garment factory with pass and fail piles.](image)
At the end of this process, the passing garments are sent to be packaged and shipped, while the failing garments are either (1) scrapped or (2) sent for rework operations. This process is inefficient for many reasons.

- In many cases, the factories are not equipped to collect data on the source of the failure. For those factories that do collect this data, the format of the data is difficult to analyze and manipulate. At the end of the production cycle, there is often no clarity on what is causing garments to fail. If the source of failure is fairly singular, all of the rework could be prevented by correcting the behavior of single operators.

- The piles pictured above are often very large. It can be days before defective products are sent to be reworked, meaning that if an operator notices that most of the defects are "crooked tags", for example, it is very likely that the tags were sewn on days before they are being inspected. There is no real-time feedback given in the process to suggest how defects can be corrected in real time.

In some more sophisticated factories, small amounts of data are collected at the endline inspection station. For the purpose of analysis, it is important to note that many of the factories visited were part of the FMEP (Fung Manufacturing Excellence Program), which is aimed at increasing the operational efficiency in some of Li & Fung’s participating portfolio factories. As such, they were at the upper end of the spectrum in terms of data sophistication and capabilities. These factories generally recognize that collecting data is important, and have defined a process to collect data at the end of the production line. This process involves the operator marking the type of defect found on a clipboard. At the end of the garment production line, an operator is responsible for inspecting garments that have been fabricated throughout the process. He/she must determine whether that garment passes inspection; if it does, a mark is placed in the “pass” column. If it does not, a mark is made in the column that corresponds with the appropriate defect characterization. At the end of the day, these defects are inputted into a computer manually, where managers hope to use the data to have a better understanding of their operations. Figure 8 shows what this clipboard method looks like in practice.
As seen in the above Figure, this process is extremely inefficient. The inefficiency stems from a few sources, as noted below:

- Operators are forced to take time to find the appropriate defect, mark the column with a pencil, and ensure they have made no mistakes.
- The inspection sheets are often in English; this is not the native language of many of the workers.
- Managers need to manually enter all of the data into an Excel sheet after the tallying for the day is over.

The above inefficiencies all contribute to a dangerously risky data collection process. In many cases, the sheets served as a convenient talking point for customers that would come and tour the factories, but were not actually entered into the computer or used for process improvement purposes. Another common byproduct of this clipboard system is that there is nothing to prevent the operators from fabricating the data. For example, since the system uses tally marks to identify
both passing and failing garments, operators would often inspect garments for a couple of hours, then guess at how many defects and passing garments they checked. They would then quickly put some tally marks in boxes to make it appear as if they had been diligently using the clipboard system throughout the process. From an incentive standpoint, there was nothing keeping the operators from doing this, and management did not seem to care. We also noticed that managers would often incorrectly input the data into their Excel models, leaving the organization at risk of leveraging bad data in their decision-making processes.

The endline inspection process is very important from a data collection standpoint, as it tells many simple metrics about the overall production process. While there are often other intermediate inspection steps through the process, the endline inspection process holds a significant amount of data related to quality, speed, and throughput. If factories are able to collect better metrics at this point in the process, it will lead to an increased understanding of cycle time and quality.

3.5 Functional Prototype Development

The first step in creating a solution to this design problem was to establish a quick way to engage the user in testing different designs of the data collection terminal. The overriding concept for the first prototype of the data collection terminal was to keep it broad; instead of testing a specific technological solution to the design problem, it was more relevant to test the method of engagement between the operator and the collection terminal. For instance, did the operator prefer to interact with a “list” of defects that they would use similarly to the clipboard? Did they prefer a visual interface? Determining the overall architecture of the user interface would be the first step in solving this design challenge. As such, a few different prototypes were created to test on-site. From an organizational perspective, it was a challenge to get management on board with the concept of taking this operator-centric view of design.

3.5.1 Management Challenges

Early in this process, different managers from within Li & Fung were close collaborators on this effort. These managers had significant experience in factories, and had a lot of good ideas that were based on their personal experience working in the textile production environment. In general, this significant experience translated into strong opinions over how the overall system should look,
feel, etc. These thoughts were all based on their own personal feelings and experiences. For instance, there was a strong desire to create a “tablet-based app” that was essentially a digital clipboard. While this may have been a fantastic solution from the manager’s perspective, it was not likely to be a user-friendly experience from the perspective of the operator.

In this case, Human-Centered Design was a powerful tool to ensure that the most optimized solution was created. Instead of hypothesizing over which design was best, it became a task of convincing management that we should include the operators in the design process and allow them to dictate which solutions they were most comfortable interacting with. This was an easier concept to sell than my personal design ideas, since the message was that the operators would have the final say in what design interface they liked.

3.5.2 Visual Defect Interface

Throughout the initial design framing process, it became clear that operators did not like the clipboard concept because it was difficult to interact with. A lot of this difficulty stems from the fact that the clipboard essentially lists out all possible defects in a table, and the operators have to flip through all of these rows to find the appropriate defect and mark it. In many cases this task is near impossible as operators sometimes do not have the literacy ability to interpret the contents of the defect table. As such, the initial concept for the optimized interface included making it extremely visual. Instead of using a table of written defects to log errors, operators should be able to indicate defect type based on a pictorial representation of the garment. Figure 9 shows the first concept for this design.
This concept was created under the assumption that in the event of a defect, operators would be able to press a button on a picture of the garment that indicates the location and type of the defect. For this to work, the following criteria had to be reasonably satisfied:

1. In order to not overly complicate the interface layout, number of defects on the garment defect interface had to be limited to \(~10\) or less. From a button placement perspective, we needed to limit the number of buttons that were on the interface in an effort to keep the layout as simple as possible.

2. All possible sources of defects had to be identified, and a determination had to be made as to whether these defects could be communicated visually. For instance, were the most important/common defects located at specific areas of the garment? Are they more general defect categories like “ripped fabric?” For the visual interface to work, it was important to determine the feasibility that these defects could be communicated in a pictorial fashion.

To determine the feasibility of these criteria, it was important to discuss the nature of garment defects with the Fung Manufacturing Excellence Program (FMEP) team. In a series of meetings,
the discussion centered on discussing the types of common defects and the commonality of these defects (determining which ones happen most frequently). It quickly became apparent that garment defects typically fall into one of three buckets:

- **Stitching defects** – these defects include problems with sewing of specific components onto the garment. Examples include “right pocket sewn incorrectly” and “tag attached crooked”. These defects can always be mapped to a specific location on the garment and account for MOST of the common defects in textile production.

- **Fabric defects** – these defects occur when the fabric itself is defective. Examples include small rips in the fabric. While they occur on a specific location of a garment, they can show anywhere on the garment since the problem occurs with the raw material fabric. Thus, they cannot be communicated visually in a repeatable fashion. These defects are relatively rare.

- **Stain defects** – these defects occur when a spot or stain is noticed on the garment. This can result from either a stain with the original fabric from the mill, or with something like an iron burn during the production process. These defects are very rare.

The idea that defects will fall into one of three categories is extremely helpful in assessing the satisfaction of the two criteria defined above. Since we have established that stitching defects account for most of the defects found on garments, and they can be communicated visually and repeatedly, the pictorial defect interface could most likely be a good communication medium for the operators. The next step was to engage the FMEP team to assess the frequency of defects on a variety of garments. First, the team looked at jeans to assess where the defects most commonly occurred. On a sheet of paper, small stickers were placed over the locations that accounted for “95%” of all stitching defects on jeans. Figure 10 shows the results of this experiment.
Figure 10 FMEP team analysis of most common stitching defect locations on jeans

Since this model was developed as including the most common defects that occur ~95% of the time, it was determined that the remaining 5% of defects would be captured using a “other” button. Similarly, fabric and stain defects would be captured using respective buttons as well that sit off of the pictorial representation of the garments. Similar experiments were conducted on shirts, sweaters, etc. and the same simple visual representation of the most common defects was created for these textiles.

3.5.3. Materials Sourcing

From the perspective of keeping costs as low as possible in the overall data collection terminal, sourcing the different electronic components was very significant to the system design.
Fortunately, since this project occurred in Hong Kong, there were many electronics markets close to the factories that were visited. From the functional prototype perspective, an Arduino Uno board was used for ease of configuring the system. Additional electronic components included wiring, red pushbuttons, green pushbuttons, resistors, and some other connectors. In Hong Kong, the Apliu Street market is well-known for its inexpensive electronics components. In nearby Shenzhen, there are massive electronics markets that are known all over the world for their cheap components and massive quantities. The components for the system prototype were acquired from Shenzhen for mere dollars, thus proving that the components were both easy to find and inexpensive to source. Figure 11 shows the electronics market that was visited to source the components.

![Figure 11 Huaqiangbei electronics market in Shenzhen, China.](image)

### 3.5.4 Functional Prototype System Performance

The first functional prototype was created using an Arduino board that interfaced with Excel as a data collection device. The Arduino board was plugged into a laptop, and communicated with a pre-defined Excel workbook over a serial connection. This was done to make the data easy to
collect, visualize, and interpret from the testing perspective of the factory managers. The data collection interface also had a significant design element for the factory managers, who needed to quickly visualize the data and make real-time process improvements based on the results. Each time a button was pressed by an operator, the time of the button press was recorded in the appropriate column in Excel that corresponded with the individual defect type. Since this data was time series event data, it was very easy to collect and display the following performance metrics:

- **Average inspection time** – this is defined as a moving average between successive button presses. It can be interpreted both as the average time it takes an inspector to check a garment, and as a proxy for the process cycle time, since it records the frequency at which garments flow out of the endline inspection station.

- **Number of passing garments** – this is recorded each time the green button is pressed and indicates how many passing garments are completed per time unit.

- **Number of failing garments** – this is recorded each time a red button is pressed and indicates how many failing garments are processed per time unit.

- **Pass rate** – this is defined as \( \frac{\# \text{ passing garments}}{\# \text{ passing garments} + \# \text{ failing garments}} \) and shows the average quality metric per time unit.

- **Failing garment breakdown** – this is an individual breakdown of garment failures. Each time a specific red button is pressed corresponding to a unique defect, this is logged in the system. A visual representation of garment defect type is shown to the managers. The purpose of this is to quickly determine the root cause of the defects and correct operator behavior in real time.

Since this data is straightforward and easy to collect, we tested different data interfaces with managers. The prototype Excel version is shown below in Figure 12.
Figure 12 Excel model visual representation of production data collected from inspector terminal

From the prototype perspective, the laptop running this Excel model was continuously updating on the endline inspection table bench. Both the operators and line supervisors could see this data in real time. If there were an unusually high number of defects, the inspector was instructed to notify the line supervisor who could then look at the data and trace the source of the defects for real time production correction.
4. User Testing

4.1 India User Testing
The first set of user data was collected in a facility outside of Delhi, India. This facility was chosen as a good candidate for user testing because the FMEP team had conducted significant engagements with the management team in the factory. They set up a “lean production line” in which garments flowed from station to station throughout the production process. This line was separate from the rest of the facility, and served as a testbed for operations projects that the FMEP team wanted to run. As such, the management was very supportive of our effort and was very open minded with giving us access to operators.

The user testing focused on two different groups: factory managers and operators. The primary goal for this first engagement was to present the functional prototype to both groups and listen to the types of questions that they asked. There were a significant number of interviews with both groups to determine where the prototype may be lacking. The following is the overall process that was employed in the factory for getting user feedback:

1. Build a prototype data platform with Arduino board, physical buttons, etc. at the factory.
2. Set it up at a endline inspection station and have a factory manager brief the operator on how to use it (and answer any questions).
3. Help the operator with the first few garments that they inspect to make sure they are using the system properly (simulates training).
4. Let the operator work with the system independently for about an hour or so, noting positives and negatives about the experience. This also allowed us to collect data on the process.
5. Factory manager would interview the operator (in native language) after the hour was up, to get their honest opinion on the platform

Figure 13 shows the team interacting with factory managers to explain the operation of the system.
In general, the most difficult part of the engagement with factory managers was trying to convey the idea that although the interface only allows the operators to select from ~10 stitching defects, these represent about 95% of all defects by frequency and was significantly better than overcomplicating the interface with unnecessary buttons. A strategy that seemed to work well was the “let’s go test it and see” theory, where if we found that through user testing a defect button was not there that should be, it could always be easily added later.

When the prototype was brought onto the production line to engage with users, there were some interesting insights that were found. Figure 14 shows the first user testing session that was conducted.
Operators loved the first prototype overall. The feedback was primarily centered on making the interface smaller / easier to use from an ergonomics perspective. Operators gave extremely positive feedback on the visual interface, and the pushbutton system. They also liked the added responsibility that came with having the data displayed at the workstation. It was interesting to watch how the operators would get excited when they pressed the green button, and disappointed when they pressed the red button. They also liked having this as a tool to communicate with line supervisors. Any time there was a plethora of defects that came to the endline inspection station, the operators could easily communicate the exact source of the defects to the managers which made it easy to fix the problem.

Figure 14 User testing in India with first prototype
4.2 China User Testing

After the first successful pilot testing in India, the team then went to a factory in Southern China to test the second iteration of the design. This time, the prototype was a bit smaller, robust, and easier to interact with. In India, for example, a common source of complaint is that the green button was too large. For the China prototype, the button was swapped out for a smaller version. In addition, the construction of the prototype was tuned to make it more robust and "solid" feeling. Figure 15 shows the upgraded prototype.

![Second prototype used for user testing in China](image)

The overall process for testing remained very similar to that in India. Overall the team was able to test the prototype with three different operators, all of whom easily understood the operation of the system. From a consistency standpoint, the team was happy that the feedback was nearly identical to that in India; operators had some cosmetic tweaks that they wished would be incorporated into the design, but loved the system functionality and operation. This user testing
occurred at the end of the internship and this system was left in the China facility to continue to collect data. During testing, the following situation occurred and is a good example of the power of having this data: In a period of 10 minutes, there were 25 garments inspected. 24 of those 25 garments were found to be defective. Due to the convenient logging of defects through the interface, it was determined that 22 of those garments all suffered from a “crooked tag” defect. The inspector was able to call over the line supervisor, who immediately looked at the data interface and saw the problem. He then went over to the operator who was in charge of sewing the tags, and had the conversation of how to improve output. From that point on, there were no more “crooked tag” defects. Without the system in place, it would have been very difficult to quantify the impact of catching this defect source quickly and easily remedying the situation.
5. Recommendations and Conclusions

5.1 Key Areas of Strategic Importance

The system outlined in this paper has some key strategic functionality for both factories and Li & Fung. This section will describe the areas in which this data collection terminal will aid the firm in its strategic priorities.

5.1.1. Real-Time Defect Analysis

In the above sections, there was a situation described in which an operator was able to clearly communicate a string of defects to the line supervisor, who in turn quickly fixed the behavior of the operator that was improperly performing their sewing operation. Essentially, a series of ~25 garments were created with a crooked tag. When the operator was checking this series of garments, they were able to easily log the defect information. When the line supervisor came by, he quickly saw the metrics displayed on the computer monitor at the inspection station and was able to quickly diagnose the production problem and correct the behavior of the operator that had incorrectly performed the stitching operation. This situation highlights the overall goal of being able to leverage process information in better diagnosing defect causes and fixing them in real time. This assumes that production flow is relatively linear and piecewise. In most garment factories, the current state is that massive amounts of inventory pile up between successive stitching operations, and thus it is difficult to establish any sort of “real-time” defect correction. Being able to correct defects in real-time has significant implications for factories in both speed and quality metrics. If factories are able to limit the number of garments that need to be re-worked and scrapped due to defects, they can theoretically complete customer orders faster and more efficiently. This will allow garment factories to become more cost effective.

5.1.2 Operator and Line Metrics

Since this system collects time series data every time a garment is collected, it becomes easy to better classify process time associated with individual operators and individual lines. If we have an idea of how quickly inspectors are checking garments, we can better understand the process cycle time since this represents the speed at which garments are exiting the production process.
Factories will be better able to understand how different operators vary in their speed of inspection, and how quickly garments flow off the line. This will give factories greater visibility into their internal operations and their process times. In factories where this data collection system is deployed on multiple lines, managers will be able to compare the cycle times of different production lines and better balance resources to achieve more even production flow.

5.1.3 Production Planning

As mentioned above, this data collection system enables the collection of cycle time information from different lines. In many cases, factories need to give customers estimated fulfillment times on their orders. Currently, these times are rough approximations based on back-of-the-envelope calculations from production staff at the factories. This data collection system will provide good historical data on exactly how long it takes to satisfy customer orders for a variety of different products. These products all have a learning curve, and it is somewhat difficult for factories to predict ramp-up times for new garments. If Li & Fung has the ability to access historical data on production times of similar products, they can better communicate fulfillment times to customers. From a network standpoint, Li & Fung would be able to access production data throughout their entire factory network. This will allow them to predict capacity and efficiency in their factories and better allocate customer orders based on historical data.

5.1.4 Lean Initiatives Validation

Li & Fung has an ongoing initiative to improve the operations of their high-value factories. The FMEP team has conducted engagements in which they help factory managers understand lean manufacturing and what tools can be used to improve productivity. In any of these lean transformation efforts, it is important to be able to quantify success and cost savings. Currently it is very difficult to establish a baseline view of how efficient factories are from a quality and time standpoint. This data system will allow for better understanding of these metrics in the base case. It will also allow for validation of lean initiatives, since the FMEP team will be able to quantify how their efforts translate to reduced scrap and improved output.
5.2 Final Design Schematic

Through the user design process, there was convergence from a usability and price perspective on what the most optimal model should look like for factory use. Figure 16 shows a rendering of the final design.

![Flexible Defect Interface](image)

**Figure 16** Rendering of proposed final design

This system consists of the device interface, a router to process the information, and the laptop that sits on the desk of the operator or manager. Essentially, this interface allows for the quick change from pants to shirts, etc. It also utilizes the wireless routers that some factories have in place. If factories do not have wireless capabilities, this is an opportunity for the factories to establish wireless capability for a targeted purpose. All of the components on the device interface can be sourced and constructed for less than $30USD.
5.3 Other Device Formats

An overriding concern of the proposed hardware solution is its ability to quickly transfer from pants to shirts, etc. In addition, when new garments are introduced to a factory, it is important for managers to easily be able to adapt the data collection interface to that new garment. As such, it was decided that the hardware solution should be adapted to a tablet-based platform in addition to the hardware version. The hardware platform has advantages that (1) operators prefer the physical buttons over the touch screen of a tablet, (2) in dusty factory environments, tablet screens can become unresponsive, (3) it is widely believed that the usability of the pushbuttons is easier to understand than the tablet interface, and (4) tablets are more expensive and more likely to be stolen. However, the tablet allows (1) more flexible customization of defect interface, (2) easier scalability and upgrade costs. Figure 17 shows the tablet-based defect interface which was contracted to an Israel-based design firm for development.

Figure 17 Tablet based defect interface layout
In the months after leaving Li & Fung for this thesis engagement, more robust requirements were drafted for the app-based interface. This effort resulted in a full-scale prototype version of the tabled-based app, which was then rolled out to a variety of Li & Fung factories. A subsequent LGO intern was tasked with managing this roll-out. Figure 18 shows the prototype tablet in use in a Li & Fung factory.

Figure 18 Prototype tablet in use at Li & Fung factory

5.4 Thesis Summary
Li & Fung’s long-term vision is to transition from a “middle man” who provides access to cheap production to a knowledge broker for its customers. They want to be able to leverage data from factories in ways that provide a competitive advantage in terms of cost, knowledge, and risk mitigation. If Li & Fung envisions their factory portfolio as a network of nodes, they want to be able to determine the output characteristics of the nodes, the risk of the nodes, the sustainability of the nodes, and capacity of the nodes, etc. Having access to this data will allow them to better
source orders through their portfolio. This is becoming increasingly important, as customers are demanding higher mix orders to be satisfied quicker than ever. The emergence of “fast fashion” has put increased pressure on Li & Fung and its production network, and the firm is trying to adjust their product offerings to satisfy this operational requirement. To be able to achieve this, they need to better understand the inner-workings of their production network from a productivity and capacity standpoint. This project is the first step in equipping their factories with the ability to collect meaningful data on the process. The data collection terminal is a simple device that provides answers to questions like “how many jeans did this factory produce today?” The backend software system that is described in Appendix 7.2 provides the framework for other sensors and data interfaces to plug into. Energy usage sensors, water quality sensors, data collection interfaces on more of the production process, etc. can all provide more clarity into the operating conditions in factories, and will enable Li & Fung to better control their supply chain. In an environment where labor rates are increasing in Li & Fung’s traditional markets, this analytics advantage can provide them with a business model to propel them into these uncertain economic conditions. It will help them continue to provide substantial value to their customers, who have more options now than ever.
6. References


7. Appendix

7.1 Arduino Code Used for Prototype

// set pin numbers:
const int buttonPin1 = 2; // the number of the GOOD pushbutton pin
const int buttonPin2 = 3; // the number of the BAD pushbutton pin
const int buttonPin3 = 4; // the number of the test pushbutton pin
const int buttonPin4 = 5;
const int buttonPin5 = 6;
const int buttonPin6 = 7;
const int buttonPin7 = 8;
const int buttonPin8 = 9;
const int buttonPin9 = 10;
const int buttonPin10 = 11;  //const int buttonPin11 = 12;
const int ledPin = 13; // the number of the LED pin

// variables will change:
int buttonState1 = 0; // variable for reading the pushbutton status
int buttonState2 = 0;
int buttonState3 = 0;
int buttonState4 = 0;
int buttonState5 = 0;
int buttonState6 = 0;
int buttonState7 = 0;
int buttonState8 = 0;
int buttonState9 = 0;
int buttonState10 = 0;
int buttonState11 = 0;  // current state of the button
int buttonPushCounter1 = 0;
int buttonPushCounter2 = 0;
int buttonPushCounter3 = 0;
int buttonPushCounter4 = 0;
int buttonPushCounter5 = 0;
int buttonPushCounter6 = 0;
int buttonPushCounter7 = 0;
int buttonPushCounter8 = 0;
int buttonPushCounter9 = 0;
int buttonPushCounter10 = 0;
int buttonPushCounter11 = 0;
int lastButtonState1 = 0; // previous state of the button
int lastButtonState2 = 0;
int lastButtonState3 = 0;
int lastButtonState4 = 0;
int lastButtonState5 = 0;
int lastButtonState6 = 0;
int lastButtonState7 = 0;
int lastButtonState8 = 0;
int lastButtonState9 = 0;
int lastButtonState10 = 0;
int lastButtonState11 = 0;

void setup() {
  // initialize the LED pin as an output:
pinMode(ledPin, OUTPUT);
  // initialize the pushbutton pin as an input:
pinMode(buttonPin1, INPUT);
pinMode(buttonPin2, INPUT);
pinMode(buttonPin3, INPUT);
pinMode(buttonPin4, INPUT);
pinMode(buttonPin5, INPUT);
pinMode(buttonPin6, INPUT);
pinMode(buttonPin7, INPUT);
pinMode(buttonPin8, INPUT);
pinMode(buttonPin9, INPUT);
pinMode(buttonPin10, INPUT);
  //pinMode(buttonPin11, INPUT);
Serial.begin(9600);
Serial.println("CLEARDATA");
Serial.println("LABEL_A,B,C,D,E,F,PASS,G,H,I");
Serial.println("RESETTIMER");
}

void loop() {
  // read the state of the pushbutton value:
  buttonState1 = digitalRead(buttonPin1);
  buttonState2 = digitalRead(buttonPin2);
  buttonState3 = digitalRead(buttonPin3);
  buttonState4 = digitalRead(buttonPin4);
  buttonState5 = digitalRead(buttonPin5);
  buttonState6 = digitalRead(buttonPin6);
  buttonState7 = digitalRead(buttonPin7);
buttonState8 = digitalRead(buttonPin8);
buttonState9 = digitalRead(buttonPin9);
buttonState10 = digitalRead(buttonPin10);
//buttonState11 = digitalRead(buttonPin11);
if (buttonState1 != lastButtonState1) {
    if (buttonState1 == HIGH) {
        buttonPushCounter1++;
        Serial.println("DATA,TIME");
        // turn LED on:
        digitalWrite(ledPin, HIGH);
    } else {
        // turn LED off:
        digitalWrite(ledPin, LOW);
    }
    delay(50);
}
lastButtonState1 = buttonState1;

if (buttonState2 != lastButtonState2) {
    if (buttonState2 == HIGH) {
        buttonPushCounter2++;
        Serial.println("DATA,TIME");
        // turn LED on:
        digitalWrite(ledPin, HIGH);
    } else {
        // turn LED off:
        digitalWrite(ledPin, LOW);
    }
    delay(50);
}
lastButtonState2 = buttonState2;

if (buttonState3 == lastButtonState3) {
    //start block here
    if (buttonState3 == HIGH) {
        buttonPushCounter3++;
        Serial.println("DATA,TIME");
        // turn LED on:
        digitalWrite(ledPin, HIGH);
    } else {
        // turn LED off:
        digitalWrite(ledPin, LOW);
    }
    delay(50);
}
lastButtonState3 = buttonState3; //end block here

if (buttonState4 == lastButtonState4) {
    //start block here
    if (buttonState4 == HIGH) {
        buttonPushCounter4++;
        Serial.println("DATA,TIME");
        // turn LED on:
        digitalWrite(ledPin, HIGH);
    } else {
        // turn LED off:
        digitalWrite(ledPin, LOW);
    }
    delay(50);
}
lastButtonState4 = buttonState4; //end block here

if (buttonState5 == lastButtonState5) {
    //start block here
    if (buttonState5 == HIGH) {
        buttonPushCounter5++;
        Serial.println("DATA,TIME");
        // turn LED on:
        digitalWrite(ledPin, HIGH);
    } else {
        // turn LED off:
        digitalWrite(ledPin, LOW);
    }
    delay(50);
}
lastButtonState5 = buttonState5; //end block here

if (buttonState6 == lastButtonState6) {
    //start block here
    if (buttonState6 == HIGH) {
        buttonPushCounter6++;
        Serial.println("DATA,TIME");
        // turn LED on:
        digitalWrite(ledPin, HIGH);
    } else {
        // turn LED off:
        digitalWrite(ledPin, LOW);
    }
    delay(50);
}
lastButtonState6 = buttonState6; //end block here

if (buttonState7 == lastButtonState7) {
    //start block here
    buttonPushCounter7++;
    delay(50);
}


Serial.println("DATA,,,,,,,TIME");
// turn LED on:
digitalWrite(ledPin, HIGH);
} else {
// turn LED off:
digitalWrite(ledPin, LOW);
}
delay(50);
}
lastButtonState7 = buttonState7;  // end block here
if (buttonState8 != lastButtonState8) { // start block here
if (buttonState8 == HIGH) {
buttonPushCounter8++;
Serial.println("DATA,,,,,,,TIME");
// turn LED on:
digitalWrite(ledPin, HIGH);
} else {
// turn LED off:
digitalWrite(ledPin, LOW);
}
delay(50);
}
lastButtonState8 = buttonState8;  // end block here
if (buttonState9 != lastButtonState9) { // start block here
if (buttonState9 == HIGH) {
buttonPushCounter9++;
Serial.println("DATA,,,,,,,TIME");
// turn LED on:
digitalWrite(ledPin, HIGH);
} else {
// turn LED off:
digitalWrite(ledPin, LOW);
}
delay(50);
}
lastButtonState9 = buttonState9;  // end block here
if (buttonState10 != lastButtonState10) { // start block here
if (buttonState10 == HIGH) {
buttonPushCounter10++;
Serial.println("DATA,,,,,,,TIME");
// turn LED on:
digitalWrite(ledPin, HIGH);
} else {
// turn LED off:
digitalWrite(ledPin, LOW);
}
delay(50);
}
lastButtonState10 = buttonState10;  // end block here
// if (buttonState11 != lastButtonState11) { // start block here
//
//  if (buttonState11 == HIGH) {
//  //
//  buttonPushCounter11++;
//  //
//  Serial.println("DATA,,,,,,,TIME");
//  //
//  // turn LED on:
//  //
//  digitalWrite(ledPin, HIGH);
//  //
//  } else {
//  //
//  // turn LED off:
//  //
//  digitalWrite(ledPin, LOW);
//  //
//  }
//
// delay(50);
//
//}
// lastButtonState11 = buttonState11;  // end block here
7.2 Tablet Technical Requirements

The following shows the technical requirements that were developed for the developer of the tablet-based version of the system. Rachel Schmidt, a fellow LGO intern at Li & Fung, assisted significantly in the development of these system requirements.

Description of Manager View Requirements and Functionality

The functionality required of the manager view is as follows:

(1) **Manage Tablet Fleet:** Allow managers to specify the number of tablets deployed on the factory floor and manage the type of garment associated with each manufacturing line (and by association, tablet). Managers will be able to update the type of garment associated with each tablet at any point in time; lines will change garment type frequently and managers will manage their tablet fleet accordingly.

![Manager View: Factory Builder Tool](image)

Figure 1: Screen rendering shows how managers will specify what items are being produced at which lines.

(2) **Create “Item ID“:** Allow managers to create an “Item ID” that associates all important item data together. The purpose of the Item ID is to provide the manager with an easy way to link a tablet on the floor to a specific garment.

   a. The Item ID associates the following information:
      i. Customer
      ii. Customer Order Number
      iii. Item Template
iv. Manufacturing Line Number (and by association, Tablet)

b. For example: There is a factory with 10 tablets deployed. Today, Tablet 7 will be inspecting “Item Template Pants” from “Customer ABC” from “Customer Order Number XYZ.” Managers need to be able to create a unique “Item ID” to link with (1) “Item Template Pants,” (2) “Customer ABC,” (3) “Customer Order Number XYZ,” and (4) Manufacturing Line which they will use to specify that Tablet 7 will be working on that “Item ID” and is fully defined.

Figure 2: Screen allows managers to create and link “Item IDs” to track garments through the quality process.

(3) Use/Create Defect Templates: Allow managers to either (1) use a pre-loaded garment defect template (i.e. “pants,” “shirt,” “dress”) or (2) create a custom template with a graphic description of the defect landscape. Whichever option is chosen will be displayed on the Operator View.

The templates will either be part of a pre-existing library (to be set up as part of the app development process and pre-loaded onto the app) or created custom by the manager if the garment type does not already exist. Each “red button” that maps to a specific defect type will need to be classified with a specific name for identification purposes on the data storage and analysis side.

a. Pre-loaded templates: We will supply visual representations of the ~10 most common garment types (pants, shirts, etc.), and the app will come pre-loaded with these templates.
b. Custom templates: Managers will be able to upload a picture of the garment, and “drag
and drop” red buttons on top of the defect locations. These red buttons will map to specific
defects, and will need to be named by managers as part of the set-up process (seen below).

![Manager View: Create New Template](image)

Manager View: Create New Template
Allows manager to build defect template. Specific actions include:
• Upload a picture to serve as the graphic for the template
• Add defect – pushing this button prompts the user to tap at the location of the defect to
crop a defect “spot”. User can then drag the “spot” to the exact
location of the defect.

Figure 3: App view allows managers to work with a pre-loaded defect template or create their own defect template

(4) **Data and Analysis:** Allow managers to see data and analysis in real-time. This data should be
aggregated for individual manufacturing lines, individual Item IDs, and overall factory level data.
Data to be displayed includes the following:
   a. Number of passing garments
   b. Number of failing garments
   c. Pass percentage (defined as passing/(passing + failing))
   d. Breakdown of specific defect root causes in both table and pie-chart view

Managers will be able to view this data on the tablet, and receive .csv records of daily data output,
for viewing on Excel.
Manager View: Data View

Allows managers to see real-time data:
- Overall factory (combination of all lines)
- Individual lines (specified by line number)
- Individual item ID (specified by item ID, combines lines producing same item ID)

Note: This is a real-time dashboard that updates at some specified interval (30 seconds). In addition, this data will need to be stored and organized in the cloud so that managers can pull historical output.

Figure 4: Data view screen rendering showing the types of analysis required for the app
Description of Operator View Requirements and Functionality

The functionality required of the operator view is as follows:

(1) **Operator Sign In:** Enable operator to associate their unique employee number with their manufacturing line.

![Employee ID Association screen rendering](image)

(2) **Access Defect Template:** Operators will see the associated “defect template” that corresponds with the unique Item ID that they are inspecting (as inputted by the manager in manager requirement #3, above). This defect template:

a. Has red buttons on the screen placed over top of the defect areas that are pushed when a defect is logged (i.e. over the back tag of a t-shirt, to be pressed if the tag is sewn on incorrectly). The red button will blink, or respond in some visual way when pushed so that the operator has visual confirmation that the logging was successful.

b. Has a large green button on the screen that is to be pushed every time a passing garment is logged. Green button will blink, or respond in some visual way when pushed so that the operator has visual confirmation that the logging was successful.

c. Displays data on-screen including pass quantity, fail quantity, and item/line number.
Figure 6: Operator Defect screen rendering

(3) **Data and Analysis:** The ability to show "data view" identical to that of manager requirement #4, discussed above (Identical to Figure 4). Pressing a "data view" button will shift the screen to the analytics interface that is shown in the manager view section and will enable line managers to see important statistics in real-time, namely:

a. Number of passing garments
b. Number of failing garments
c. Pass percentage (defined as passing/(passing + failing))
d. Breakdown of specific defect root causes in both table and pie-chart view

**Data Storage, Visualization, and Analytics Requirements**

Data is to be stored on Amazon Web Services (AWS), and accessed through both the application in real-time and for consumption in .csv or other applicable format for consumption in Excel remotely. Every time a "green" or "red" button is pressed, the following information will be stored and collected:

- Customer / Customer Order Number
- Item Type
- Manufacturing Line Number
- Operator Employee ID
- Timestamped Pass Indicator (if garment passes)
- Timestamped Fail Indicator of SPECIFIC Defect Type (if garment fails)
Collecting these data points will enable the following analytical outcomes:

- Breakdown of specific defect types (to be displayed in table and pie chart on app)
- Cumulative numbers of both passing and failing garments
- Pass percentage
- Average inspection time

Table 1: A mock schema could look something like this (open to suggestions)

<table>
<thead>
<tr>
<th>Customer Order Number</th>
<th>Item Type</th>
<th>Line Number</th>
<th>Operator Employee ID</th>
<th>Date</th>
<th>Pass</th>
<th>Right Leg Stitch (defect 1)</th>
<th>Left Leg Stitch (defect 2)</th>
<th>Inner Seam Stitch (defect 3)</th>
<th>Outer Seam Stitch (defect 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC123</td>
<td>Shirt</td>
<td>1</td>
<td>XYZ</td>
<td>Nov 8 2017</td>
<td>10:23:18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABC123</td>
<td>Shirt</td>
<td>1</td>
<td>XYZ</td>
<td>Nov 8 2017</td>
<td>10:24:48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABC123</td>
<td>Shirt</td>
<td>1</td>
<td>XYZ</td>
<td>Nov 8 2017</td>
<td>10:25:30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 shows a pictorial representation of how the data could be stored. The defect data categories (right leg stitch, etc.) all map to specific red buttons on the defect template. The table will populate with defects based on the manager’s setup of the specific custom defect template.

This pictorial table represents three separate button pushes: one “pass” at 10:23:18, and two “failures” of different types, at the logged times. This database will need to breakdown the data based on the headings listed (Customer Order Number, Item Type, etc.) so that the data can be easily viewed by manager.

**System Risk Discussion**

This section will present a brief overview of data logging risk.

In many factories, Wi-Fi will likely be inconsistent, and may prevent the ability to continuously transmit data to the router and thus to the AWS server. The developer will need to present a plan that identifies the following:

- What happens in the event of a Wi-Fi connection failure?
- How do we ensure that data will be consistently aggregated in the event that an individual tablet is “offline” for a certain period of time?
- How frequently are the tablets communicating to the AWS server?
- What is the overall system capacity in terms of tablets deployed in a given factory based on the system design, nominal router, and database storage capabilities?