Electrical Engineering Department
California Polytechnic State University

Senior Project Final Report

PolyOne Smartphone

June 2020

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Abstract

The PolyOne Smartphone aims to design, build and test the first Cal PolyOriginal smartphone. The foundation for the project intends to explore the technology behind pre-existing smartphones and look in-depth between LTE and 5G communication mediums to weigh the feasibility and potential benefits. 5G is the latest generation of wireless technology, and promises faster data transmission speeds, lower latency, and the ability to connect more devices. These improvements will enable the implementation of new technologies that take advantage of the faster speeds and increased connectivity that were not available with 4G, as well as increase the potential for integration of 5G into other Internet of Things(IOT) systems such as home internet.

With the introduction of 5G, a major goal is to build an affordable prototype that explores the improvements that 5G brings and discover and address any issues that may come with it. Another goal of the PolyOne Smartphone is improved privacy. While the growth of IOT and the ability to be connected to the internet nearly anywhere makes many things easier and more accessible, there is also a concern with the exposure of personal information that comes with an easily accessible medium. The PolyOne Smartphone aims to address some of these privacy concerns in hardware to make it easier for users to control phone privacy.

The key features of this smartphone are network connectivity (Wifi, Cellular), a rechargeable battery that works with common power connections, and compatibility with popular apps such as Facebook, YouTube, and Spotify. Possible features that can also be researched include flexible technology and bluetooth connectivity. Another emphasis for the prototype is efficient energy usage and robust privacy options. We believe there is a market for smartphones that have longer battery lives and more clarity with regards to when the phone is using GPS, microphones, and cameras. We aim to achieve increased clarity about when the phone is accessing these types of data by including physical kill switches for each of these modules.
General Introduction and Background

A smartphone is a mobile phone that performs many of the functions of a computer, has a touchscreen, has internet access, and is capable of running apps [5]. The first smartphone, the Simon Personal Communicator, was released in 1992 by IBM. For $1000, it offered a monochrome LCD touch screen, an hour of battery life, email, fax, and could be used with a few apps. Although it did not sell well, it was very advanced for its time and would be the starting point for a revolution in personal electronics. The first “modern” smartphone would not appear until 2007 with the release of the iPhone.

The iPhone was revolutionary for the no keyboard full screen design and provided users with internet access, 8 hours of battery life, and was one of the first devices that used 3rd party apps, giving phones the capability to be modified to personal tastes [6]. Around this time, smartphones began becoming more than just a phone, and moved towards a personal computer that is used in daily life. Today, smartphones are more prevalent than ever, with 81% of Americans saying they own smartphones [4]. Since the original iPhone, there have been numerous improvements to all aspects of smartphones, including memory, speed, power, battery life, and application use. With the increase in capabilities of smartphones, they have become infinitely more useful than the original Simon Personal Communicator and for some, a necessity for everyday life. Smartphones are an essential part of many people's lives in today’s modern society. When people leave the house, they constantly grab their keys, wallet, shoes, and smartphone every day. Most people have a deep emotional connection to their smartphone and some even have withdrawals from not having it. The smartphone has changed how humans...
communicate by allowing people to be connected 24/7. For many, it is difficult to do well in school or work without one because teachers and clients and bosses utilize smartphones to give instructions. Smartphones will only become faster and more powerful in the future, having the potential to enable new technologies and create a more connected world. This increase in capability will only make it a more important tool in everyday life, and the PolyOne Smartphone intends to meet these needs by implementing the newest wireless technology while still addressing privacy concerns that will come with a more connected world.

The infrastructure for 5G has begun to be developed in the United States, and the implementation of 5G will bring big changes to smartphone technology. 5G is the newest wireless protocol, replacing 4G. Mobile networks are what enable phone users to connect to the internet and hand off packets of signals such as voice, data, and texts.

The first mobile networks were only able to deliver voice, and later versions added mobile data and internet capabilities. The latest version is 5G and it mainly brings increased speeds, lower latency, and more connectivity. The increased speeds will be seen by most users in shorter download times for video and files, and also means that streaming high-definition video will improve as well. The low latency and connectivity will bring in a host of new applications ranging from improving smart devices to augmented and virtual reality. The 5G infrastructure requires more coverage than 4G, and needs the installation of many small cells that can be deployed on street lights[2]. Although the 5G protocol has been confirmed, the technologies are still very much in development and PolyOne Smartphone intends to be one of the first low cost options for 5G.

Figure 2 : Small Cell [2]
Product/Project Description

The PolyOne Smartphone is a student designed smartphone built to explore the implementation of 5G, provide a hardware solution to ensure personal information security and privacy, and provide longer battery life. The key features of this smartphone include but are not limited to a main cpu, some form of network connectivity in the form of Wi-fi or Cellular Data, calling functionality, a rechargeable battery that works with common power connection protocols, and compatibility with popular applications.

The PolyOne Smartphone functions similar to any smartphone but pays special attention to 5G and privacy applications. With 5G infrastructure beginning to appear in the United States, it is an exciting time to be involved in the smartphone market. 5G brings increased speeds, improved latency, and will provide the resources to build better, faster, more connected applications and systems. With the appearance of 5G there is a demand for better performing hardware that is capable of handling the increased speeds. But, with increased connectivity, there is also a concern for the security of personal information and the ability to have control over smartphone privacy. The PolyOne Smartphone attempts to solve this by providing a hardware switch that turns off circuitry that controls location and data sharing functionalities.
Product Research

Smartphones are one of the most popular electronic devices out in the world. As such, there are many different products that are out in the market, from Apple’s iPhones, Samsung’s Galaxy models, etc. Each model has increasingly grown complex over the years as a result of the technological advances in the electronics industry.

Figure 5, 6: Apple’s iPhone 11 and Samsung Galaxy A70 Smartphones

5G systems are an up-and-coming technology in today’s modern smartphones. From a consumer perspective, the newest models of Samsung’s Galaxy, OnePlus 7, and Huawei Mate product lines have 5G capability [16]. From a developer standpoint, AT&T, Verizon, Sprint, and T-Mobile all have 5G towers, but the distribution network is still limited, with coverage exclusive to select major cities in America [17].

While these systems grow increasingly complex with the advance of technology, there hasn’t been as much growth for the privacy safeguards as there should be. There are currently no popular hardware safeguards against privacy issues such as unauthorized camera or microphone usage.
Technology Research

For the PolyOne Smartphone, the technology does exist for 5G communication. 5G is a new generation of wireless technology [18]. Actually called 5G-NR, it currently has a symbiosis relationship with its predecessor, 4G, to make the “initial connections before trading up to 5G where its available” [18]. 5G operates above and below 6GHz, where lower frequency bands have high ranges from towers, while high frequencies have a significantly faster speed than 4G. 5G relies on a type of encoding, known as OFDM [19], where a single data stream is separated into different narrow bands at different frequencies to reduce signal interference [19]. 5G currently is 30% more efficient than 4G when using the same airwaves, with the improvement attributed to better encoding methods. Overall, 5G stands to be around 10x faster than the current standard, 4G/LTE Advanced.

![Downlink Speeds by Technical Generation](image)

**Figure 7: 5G vs Predecessors Speed Comparison**

Privacy continues to be a very controversial topic, especially for owners of electronic devices that they take everywhere. However, with all the debate of companies’ access to private information, there seems to only be a remedy in terms of software permissions that can be revoked, and data encryption [20]. The PolyOne Smartphone plans to take these safeguards to a simpler fix, as there will be manual kill switches that dictate whether or not power is supplied to peripherals such as cameras and microphones.
Market Research

When compared to other main smartphone manufacturers, the PolyOne smartphone will be very similar to the competition, yet unique in its own right. 5G is an up-and-coming innovation that will revolutionize the smartphone industry with never-before seen data transmission speeds. Currently, Huawei, Samsung, LG, and OnePlus each have 5G compatibility on their devices, with Apple expecting to adapt as soon as 2020. However, all of these companies only have 5G capability in their top of the line models of smartphone. PolyOne aims to provide an affordable alternative to these products, which would save customers hundreds of dollars.

Privacy concerns have always been a cause for concern with the ascent of smartphone technology, but recent events have fueled renewed debate as to how often is our electronic device operating without its owners’ consent. The only safeguard is intricate data encrypting that protects our personal data from unauthorized users, but there is no clear safeguard for information regarding our location and communication when owners are not using their smartphone. With the installation of a physical switch, consumers can rest assured that their cameras and microphones will not be collecting background data as the switch will control the power supply of both peripherals. This switch is a cheaper and simpler alternative compared to more complex software fixes to privacy concerns.
Customer Archetype

The PolyOne Smartphone has many established main competitors in the market; however, most of them are several hundred dollars more in cost and do not have 5G technology implementation and a hardware solution to provide protection for personal information and privacy. By putting a greater emphasis on low cost, simple user friendly UI, high speeds, and privacy protections, the PolyOne Smartphone will be able to cater to many different types of customers in the market. The types of customers include: Early Adopters, Heavy Usage/Privacy Concerned Phone Users, Parents with Young Children, Elders, and Cal Poly Students. With the growing trend towards high speed connections as well as low cost and simplicity, the PolyOne Smartphone will bring many features that these customers will find attractive and beneficial to their needs.

<table>
<thead>
<tr>
<th>Type of Customer</th>
<th>Description</th>
<th>Reason</th>
<th>Product Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Adopters</td>
<td>Early Adopters are generally people who enjoy and adopt new technologies or products that were recently introduced into the market.</td>
<td>The new 5G technology and implementation as well as the privacy protection solution will attract many Early Adopters as not many smartphones in the market have these features.</td>
<td>They will use this smartphone in their everyday lives, provide the company with vital feedback to help make improvements and refinements, and help move the product mainstream.</td>
</tr>
<tr>
<td>Heavy Usage &amp; Privacy Concerned Phone Users</td>
<td>These customers are those who use their phone frequently throughout the day and require high speeds for their work and personal consumption. Additionally, they value the need for data privacy.</td>
<td>The longer battery life, hardware solution for personal information and privacy protection, and the high speed 5G connection will be beneficial for these users.</td>
<td>They will be used for work, business, and personal consumption.</td>
</tr>
</tbody>
</table>


Parents with Young Children | These are people who want some form of phone connection for their young children. | Parents will find this inexpensive, secure, and user friendly smartphone attractive for their children. | Young children will use it for their everyday lives, communication with their parents, and for academic purposes.  
---|---|---|---
Elders | Elders are adults over 75 and want a simple smartphone for communication. | The simple, user friendly UI and communication will be appealing for elders. | They will be used for personal consumption and communication with other people.  
---|---|---|---
Cal Poly Students | Students at Cal Poly | The reverse engineering aspect as well as the new and unique technology may be useful and beneficial for students. | Students will use it for reverse engineering and phone deconstruction as well as for personal and school use.  
---|---|---|---
**Table 1. Customer Archetype.**

<table>
<thead>
<tr>
<th>Market Leader</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Apple Logo" /></td>
<td><strong>Apple Inc.</strong> is one of the Big Four tech companies in the U.S and is known for developing and creating consumer electronics and computer software. The iPhone, which debuted in 2007, was the first smartphone designed by Apple and set the basis for current smartphone designs. Apple has not officially announced 5G capability for the iPhone [10].</td>
</tr>
<tr>
<td>Company Name</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Google LLC</strong></td>
<td>known for their internet-related services and products, search engine, software, and hardware products. The Pixel serves as the first smartphone developed by Google and recently introduced into the market in 2016. No 5G support has been announced for the Pixel smartphone line so far [11].</td>
</tr>
<tr>
<td><strong>Huawei Technologies Co., Ltd.</strong></td>
<td>a Chinese company responsible for selling telecommunications equipment and consumer electronics including smartphones. In 2018, Huawei became the second largest smartphone manufacturer in the world. Huawei’s Mate 20 X has 5G capability [12].</td>
</tr>
<tr>
<td><strong>LG Electronics Inc.</strong></td>
<td>a South Korean electronics company known for products for home entertainment, mobile communications, home appliances, and vehicle components. The LG V50 ThinQ was launched in 2019 and has 5G support [14].</td>
</tr>
<tr>
<td><strong>OnePlus Technology Co., Ltd.</strong></td>
<td>a Chinese company known for their smartphone line called OnePlus. OnePlus One was its first smartphone and introduced a lower cost for similar specifications of other flagship smartphones. The OnePlus 7 Pro will have 5G support [13].</td>
</tr>
<tr>
<td><strong>Samsung Electronics Co., Ltd.</strong></td>
<td>a South Korean electronics company that specializes in consumer electronics, semiconductors, and other electronic components. The Samsung Galaxy S series is the company’s flagship smartphone. The Galaxy S10G, priced at $1299, has 5G capability [15].</td>
</tr>
</tbody>
</table>
Table 2: Market Leaders/Industry Competitors

According to Statista.com, in 2018, about 1.56 billion smartphones were sold to end users worldwide [21]. As smartphones become more advanced with more computing capabilities and faster connectivity than regular mobile phones, more people are buying smartphones. Growing interest in new technologies and additional features and improvements for personal use in smartphones have led to the market expanding. However, flagship smartphones have been continuing to be more expensive on release. The PolyOne Smartphone will be able to address this problem by providing a lower cost but also similar features and benefits as others.
**Market Description**

Our product aims to provide a new Cal Poly designed smartphone that is focused on performance and privacy. Our designs will utilize the fastest network protocols to deliver the streamlined experience expected by smartphone users at a lower price point than the high end smartphone market demands.

The PolyOne smartphone will be driven by the desire for transparency regarding privacy. Our goal is to include hardware switches that allow the customer to fully decide when they want to turn off the microphone, camera, and GPS tracking.

<table>
<thead>
<tr>
<th>Limitations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Software</strong></td>
<td>Our team does not include any students proficient in software development. This could prove to be a severe challenge if we want to implement an original operating system or any oritional applications.</td>
</tr>
<tr>
<td><strong>5G Technology</strong></td>
<td>5G technology is not fully established in the United States so we will run into some challenges preparing the device for 5G connectivity. Most smartphone companies have some connection to the people who are developing the 5G protocol so they have additional knowledge on how the protocol will operate</td>
</tr>
<tr>
<td><strong>Parts that are not commercially available or are too expensive to buy for prototype units</strong></td>
<td>Smartphone companies take advantage of economies of scale by ordering expensive parts in bulk and getting discounts per unit. If we order products individually, there is a high potential for the price to go up</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td>We have limited manufacturing resources and therefore the product</td>
</tr>
</tbody>
</table>
we develop will likely be larger than other smartphones on the market. We can design and print printed circuit board assemblies externally but our connections will likely have to be large enough for us to connect or solder by hand.

<table>
<thead>
<tr>
<th>Time limitations</th>
<th>We are limited by a strict deadline of when we need to design and prototype the product. This will be delayed by all parts that need to be shipped from China so we will need to develop our component list early on and order parts as soon as possible.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proprietary information</td>
<td>Smart phone companies have a large amount of patents on their technologies making the smartphone space a difficult realm to enter. We may have to navigate free to use parts or look into royalty based options.</td>
</tr>
</tbody>
</table>

Table 3: Limitations.

Our key strength is our visibility regarding privacy and our hardware kill switches. Our competitors allow large companies to use location data to build profiles on their users, many times without the knowledge of the customer. With our phone, the customer will have full control of the camera, the microphone, and the GPS data with the built in hardware kill switches.

An area of the market that we are not competitive is the high end ultra high performance smartphone market. This segment of the market is dominated by professionals with specialized camera softwares that create perfect photos and specialized microprocessors that allow for cutting edge speeds. Without the know-how or the manufacturing resources, we will not be able to compete in this market.

The window of opportunity for our product is now until a competitor comes out with a robust DIY smartphone design that gains public traction. Once the market becomes established, it will become saturated quickly. Our customer archetypes will all react differently depending on
how the competitors choose to advertise. DIY enthusiasts may latch on to a competitor’s DIY smartphone product if it comes to market before ours. Also, new phones are theoretically coming out soon with more comprehensive (hardware based) privacy solutions. The customers who value privacy may opt for these phones when they come out. There would still be a market for parents who seek a simplistic smartphone for their kids and elderly people who want a simple alternative to the complicated smartphones available on the market.

To penetrate the market, we would have to put serious capital into advertising and manufacturing. If we accomplished a successful implementation of a prototype, we could enter the market initially as a DIY smartphone company where tech minded people can put their skills to the test by recreating our prototype on their own. To do this, we would need a few thousand dollars. We estimate our entire design to cost under $1,000. Marketing the final design will require another $1,000 to have a successful rollout.

To have the most successful implementation possible, we could utilize some organizations as key partners. If the product is well suited to academic uses, we can convince Cal Poly to buy a device for each new student. Two key partners in the EE department are professor Murray and Dr. Derickson. We can also work closely with old age homes where we can host seminars on how to use our phones. One key partner from a local old age home in SLO is Pita, who organizes events for the elderly at the facility.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased privacy measures (kill switches)</td>
<td>Not as well designed or tested as current market dominators</td>
</tr>
<tr>
<td>DIY learning opportunity</td>
<td>Not as small or sleek as leading smartphone models</td>
</tr>
<tr>
<td>Replaceable battery</td>
<td>Not as good of a support system for people who need help</td>
</tr>
</tbody>
</table>

Table 4: Advantages and Disadvantages.
## Marketing Requirements

<table>
<thead>
<tr>
<th>Marketing Requirement</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affordable Cost (Priced at $349.99)</td>
<td>This will offer a cheaper price point than more expensive ultra high performance smartphones</td>
</tr>
<tr>
<td>NETWORK Technology: GSM / GPRS / CDMA / HSPA / EVDO / EDGE / LTE (2G, 3G, 4G, 5G capability)</td>
<td>These requirements are important so users can connect their phones to a larger cellular network</td>
</tr>
<tr>
<td>Camera</td>
<td>Some people buy phones because they have good cameras</td>
</tr>
<tr>
<td>Removable/Rechargeable Battery</td>
<td>It needs to be rechargeable to offer a more sustainable and comfortable user experience. It should be removable so that the phone can last longer and the battery can be replaced if it goes bad</td>
</tr>
<tr>
<td>Capacitive Touch Screen/Ink Display</td>
<td>This is basically a hallmark of modern smartphones</td>
</tr>
<tr>
<td>RAM</td>
<td>RAM is necessary so the phone can compute complex instructions quickly</td>
</tr>
<tr>
<td>Memory</td>
<td>Memory is important because people will need to store things on their device</td>
</tr>
<tr>
<td>Hardware Privacy Switch</td>
<td>This is one of the main design features of our product. People may buy our product because of this design choice.</td>
</tr>
</tbody>
</table>

Table 5: Marketing Requirements.
The PolyOne Smartphone design will implement features that improve usability as well solve current problems that customers see within the smartphone design. Like current smartphones, the PolyOne Smartphone will have some features such as calling functionality, network connectivity, and apps compatibility. However, in order to stand out from other products in the market, the smartphone will prioritize implementing 5G technology, long battery life, and privacy protection solutions.

<table>
<thead>
<tr>
<th>Importance</th>
<th>Design Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>5G Support</td>
</tr>
<tr>
<td>High</td>
<td>Rechargeable Battery with Long Battery Life</td>
</tr>
<tr>
<td>High</td>
<td>Hardware Switch for Privacy Protection</td>
</tr>
<tr>
<td>High</td>
<td>Calling Functionality</td>
</tr>
<tr>
<td>High</td>
<td>Network Connectivity</td>
</tr>
<tr>
<td>Medium</td>
<td>Apps Compatibility</td>
</tr>
<tr>
<td>Medium</td>
<td>Phone Size</td>
</tr>
<tr>
<td>Low</td>
<td>Ink Display</td>
</tr>
<tr>
<td>Low</td>
<td>Camera</td>
</tr>
</tbody>
</table>

Table 6: Customer Needs with Importances.
Block Diagram, Requirements, and Specifications Section

The high level black box diagram includes the inputs and outputs of the smartphone. The inputs consist of power, user input, audio input for calls, and any wireless communication needed. The outputs include video data displayed on the screen, audio output for calls, and wireless communication.

![Level 0 Block Diagram](image)

**Figure 8: Level 0 Block Diagram**

The level 1 block diagram goes one level up in complexity and shows major functional blocks of the smartphone. Some things to note are that the hardware switch is included in user input and directly connected to power and that the power electronics and distribution is connected to all components needing power.

![Level 1 Block Diagram](image)

**Figure 9: Level 1 Block Diagram**
Engineering Requirements

The engineering requirements quantify the marketing requirements and provide exact specifications that we can meet so that we can be confident that we have successfully achieved the marketing requirement standards. The list is not all inclusive but does highlight some of the key requirements we want to emphasize.

<table>
<thead>
<tr>
<th>Engineering Requirements</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥24 hours of normal use</td>
<td>Large battery is a key feature with 2000 mAh being a lot larger than current products. [22]</td>
</tr>
<tr>
<td>≥2000 mAh</td>
<td></td>
</tr>
<tr>
<td>Operate from 3.7V Source and charge from</td>
<td>Typical Cell Phone battery and charging voltage source</td>
</tr>
<tr>
<td>5V USB</td>
<td></td>
</tr>
<tr>
<td>Mechanical Switch that turns off Power to</td>
<td>Key Feature of Product. With privacy being a key focus for a product, the best way to ensure to customers that privacy is kept is through tactile switches.</td>
</tr>
<tr>
<td>GPS, camera, and microphone Modules</td>
<td></td>
</tr>
<tr>
<td>The dimensions should not exceed 16cm x 9cm x 2cm</td>
<td>The smartphone should be pocket sized to match modern products, yet large enough to be readable for people with slightly impaired vision</td>
</tr>
<tr>
<td>Must be able to make calls over a network</td>
<td>A basic phone functionality</td>
</tr>
<tr>
<td>Wireless data connectivity</td>
<td>Basic feature of modern smartphones</td>
</tr>
<tr>
<td>Button or touch screen allows interface with phone</td>
<td>The smartphone will have a simpler UI/UX interface that appeals to the desired demographics</td>
</tr>
</tbody>
</table>

Table 7: Engineering Requirements
Testing and Verification

≥24 hours of normal use and ≥2000 mAh:

The 2000 mAh requirements is something that can be confirmed by setting up a test bench that draws power from the battery and we can measure the amount of time it takes until the battery discharges at a specific load. To test for 24 hours of normal use, the phone can be tested by a “user” or the battery can be tested by simulating the current draw. The first test would simply require a person to use the phone throughout the day as they would a normal phone and see if it lasts the full day. The advantage of this test is that the phone would be tested live and in an environment outside of a lab. The second test would require a programmable electronic load that could be programmed to simulate the power drawn during the day when the phone is used. The advantage to this test is that the battery can be stress tested and it is easier to obtain large amounts of data on more than one product. In addition, not needing to have a person operating the phone will allow us to run the test over multiple days and if we can get access to an oven we can test it at different temperatures.

Operate from 3.7V Source and charge from 5V USB:

This is a functional test. Can also test tolerances on input voltage charging (5V +/- XX%).

Mechanical Switch that turns off Power to GPS, camera, and microphone Modules:

This is a functional test. See if switch safely turns off components. This would require turning on and off the switch and 1) ensuring the correct modules turn on/off and 2) Using the switch does not damage the performance of the modules in long term.

The dimensions should not exceed 16cm x 9cm x 2cm:

This is a functional test.

Must be able to make calls over a network:

This is a functional test.

Wireless data connectivity:

This is a functional test.

Button or touch screen allows interface with phone:

This is a functional test.
Team Project Roles

**Systems integration and i/o - Gerome Cacho**

This role consists of obtaining major functional modules of the phone and the connection protocols associated with each part. This will require doing a breakdown of the phone kit to better understand smartphone systems. This role specifically will focus on the power distribution of the subsystem.

**Systems integration and i/o - Chris Lim**

This role consists of obtaining major functional modules of the phone and the connection protocols associated with each part. This will require doing a breakdown of the phone kit to better understand smartphone systems.

**Systems integration and i/o - Chi Nguyen**

This role consists of obtaining major functional modules of the phone and the connection protocols associated with each part. This will require doing a breakdown of the phone kit to better understand smartphone systems. This role specifically will focus on the audio and dsp subsystems.

**RF Systems - Josh Zalmanowitz**

This role focuses mainly on the wireless technologies of the phone and obtaining or designing the necessary hardware for it.
Figure 10: Gantt Chart through June 2020
Cost (BOM)

The PolyOne Smartphone will require funding from Cal Poly’s Electrical Engineering department. The funding will be used for the components listed below in Table 8.

<table>
<thead>
<tr>
<th>Bom Level</th>
<th>Part Number</th>
<th>Part Name</th>
<th>BOM notes</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>Poly1 Smartphone</td>
<td>The full smartphone device</td>
<td>235.9</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Wifi Connection</td>
<td>Included on RPi</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>Microphone</td>
<td>Mini Mic for R. Pi</td>
<td>6.99</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>Speaker</td>
<td>Pimoroni Speaker</td>
<td>19.99</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>GPS chip</td>
<td></td>
<td>12.99</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>Modem (Cellular)</td>
<td>NOVA usb modem</td>
<td>75</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>Memory</td>
<td>SD card reader</td>
<td>7.50</td>
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<tr>
<td>1</td>
<td>8</td>
<td>Battery and power management</td>
<td>Battery 2000 mAh 3.7V</td>
<td>12.50</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>Microcontroller</td>
<td>Raspberry Pi</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>LED or LCD interface</td>
<td>R Pi touchscreen 320x240</td>
<td>42.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Camera</td>
<td>8 megapixel</td>
<td>21.23</td>
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<tr>
<td>---</td>
<td>---</td>
<td>----------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>Buttons</td>
<td>generic numerical keypad</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Table 8. Bill of Materials.
Analysis of Senior Project Report

Project Title: PolyOne Smartphone

Students’ Names: Gerome Cacho, Chris Lim, Chi Nguyen, Josh Zalmanowitz

Advisor’s Name: Prof. Richard Murray

Summary of Functional Requirements

The PolyOne Smartphone is a smartphone that aims to explore the benefits and drawbacks of the 5G technology implementation as well as to provide a hardware solution for privacy protection and personal information security. It will be powered by a rechargeable battery of at least 2000mAh, have a mechanical switch for turning on and off GPS, camera, and microphone modules, and have basic phone functionalities such as calling/texting and wireless network connectivity. The main purpose of this smartphone is to have higher speed connection through 5G, have more user control privacy, and longer battery life.

Primary Constraints

One primary constraint that this smartphone is the software and OS. Our team does not have proficient experience in software development to create the phone’s own advanced OS or applications on it; it will need to use a very basic and simple OS. Another constraint is the dimensions and size of the phone. We will need to stick to a certain dimension to fit all the components that we need.

Economic

a. Human Capital: The PolyOne Smartphone can generate capital by producing jobs in many sectors such as engineering, assembly, sales, marketing, and manufacturing.

b. Financial Capital: Our target customers will be able to use our smartphones for personal and work consumption at a much lower and affordable price compared to our competitors.

c. Natural Capital: This product will contain many electrical and mechanical components including a CPU, RAM, screen, battery, camera, and mechanical switches. Some of these parts will be difficult to recycle and dispose because of the material used to make them.

d. Cost and Timing: The cost of the PolyOne Smartphone is heavily dependent on the hardware and electrical components. We have an estimate of about $135 for the phone to
be built but the cost may change as we change the design and buy different smartphone kits. This would also affect the retail price.

If Manufactured on a Large-Scale Basis

Estimated Number of devices per year: 10k
Estimated manufacturing cost for each device: $135
Estimated purchase price for each unit: $349.99
Estimated profit per year: $2,150,000
Estimated Cost for User to operate devices: $1  (Electrical Cost)

Manufacturability

The PolyOne Smartphone will only need manufacturing of the physical outer casing. It will mainly require assembly of various components purchased from vendors and then wired and interfaced together with leads and soldering.

Environmental Impact

The PolyOne Smartphone will have a notable environmental presence at the beginning and end of life phases of the product due to the materials of the device. It must be noted that during the middle of life phase, the consumer life cycle, the energy consumed by the product will have an impact on the environment due to the added demand for electricity, but this effect is miniscule compared to the electricity demand from other electronics. Another environmental impact is that some of the components are made of rare materials like copper, tin, aluminum, gold, etc [23]. As these electronics are in widespread demand, the amount of material mined in the world’s quarries have grown exponentially to satisfy the demand. Additionally, electronics that are disposed worldwide account for nearly 70% of the toxic waste in landfills [24].

Sustainability

When designing and manufacturing electronics, it is important to keep sustainability front and center in all design choices. To avoid our devices ending up in landfills, we need to ensure they have long consumer life cycles and high quality components that will not break down or need replacement. Ideally, our customer will be able to buy our product and use it to meet all of their smartphone needs for years without the need for replacement parts. Unfortunately, our product has had to sacrifice increased sustainability in some cases to achieve some of our goals,
such as our decision to use a rechargeable mobile battery rather than a more sustainable plug in option that would never need replacement.

**Ethical**

The device has some ethical concerns, primarily regarding user health and environmental impact. In regards to user health, the extended use of the product can result in damaging effects. The PolyOne Smartphone is designed to have a higher battery life than the current market competitors, which could lead to a higher usage rate than the competitors. This could have adverse effects on vision. Additionally, extended smartphone sessions can lead to addiction and cause mental health detriments. There is also the societal impact of people using their phones instead of speaking face to face with one another. Environmental concerns stem from the materials used in creating electronics and the fact that electronic waste (aka e-waste) accounts for nearly 70% of toxic waste in landfills today. The physical killswitches for the devices lead to a manual control of location data as well as camera and microphone usage. While this guarantees privacy for users who require it, there are also drawbacks as in the wrong hands, this device can potentially be used to mask the location and details of crimes and make criminals more untraceable.

**Health and Safety**

The safety concerns regarding the PolyOne Smartphone are similar to any electronic device. With prolonged use of the device, which is further exacerbated by the larger battery of the PolyOne Smartphone compared to its competitors, the user puts themselves at a higher risk of vision issues such as myopia and asthenopia. It is up to the user to understand the risks and be able to properly use the device sparingly as to avoid overuse of their eyes.

There are also psychological effects to users’ health, as a larger battery would further increase the dependence on technology by the user. As the PolyOne Smartphone is marketed to the elderly and younger demographics due to the simplistic UI/UX design, having these age ranges further exposed to technology would have a severe impact on their socialization skills, especially the latter demographic. In addition, through longer use of the PolyOne Smartphone, this would further empower any users who have addiction to phone usage, social media, gaming, or gambling. As another feature of the PolyOne Smartphone is compatibility with mainstream applications, having prolonged access would only further impact people’s attachment to these channels.

**Social and Political**

Similar to ethical issues, some social and political issues might arise from daily use of the PolyOne smartphone. Extended use of this product can lead to damaging and adverse effects
such as poor vision, addiction, and mental health detriments. Proper and ethical use of the smartphone must be enforced and present or legal issues might occur.

This project has an impact in regards to numerous stakeholders in the smartphone and technology industry as well as other smartphone competitors in the market. Direct stakeholders are consumers who are heavy usage and privacy concerned phone users and are interested in 5G technology. Indirect stakeholders are other phone users since this device could drive smartphone prices down. Retail and online channels will also be affected due to lower cost of the PolyOne smartphone.
Preliminary Design Analysis

For the initial process, a DIY phone kit was purchased in order to get more comfortable with the basic systems needed in a cell phone. When choosing a kit to purchase many factors were considered including but not limited to cost, availability, brand, user reviews, wireless capability, prebuilt vs DIY, and ease of reverse engineering. It was important to get a kit that had discrete functional blocks and would allow us to look at separate functional blocks.

We finally decided on the CircuitMess Ringo 4G Kit | Build Your Own Mobile Phone | Do-It-Yourself Project and will base our phone design off of this kit.

The major portion of the design will be done in winter quarter when we design the hardware switch and look at the wireless 5G technologies. This will require further research on 5g and 4g technologies as well as looking at what is currently available on the market. The hardware switch will be either power focused or controlled by the microcontroller, and will have an emphasis on systems connectivity for controlling each of the modules that we want controlled by the privacy kill switch.

Initial Enclosure Design

The following pictures are of our initial phone enclosure design. The dimensions of this original design is 4 x3 x1.5 inch, which is much larger than that of our engineering specifications. This design will need to be reduced in size in the future but was a general idea for the enclosure that we desired early into the design phase.

Figure 11: Solidworks CAD model
Figure 12: Solidworks CAD model

Figure 13: Preliminary Enclosure Print

Figure 14: Preliminary Enclosure Print
Addendum 1

Since the end of Fall Quarter, the PolyOne smartphone team has been hard at work identifying possible components to use in the implementation of the phone. Through a significant research effort, our team was able to find seven teams that have the same goal of creating a DIY phone. Some of the teams were more far along than others, but all seven provided useful information to our group. One company that stood out among the rest was CircuitMess, a DIY enthusiast group located in Croatia. They have put significant effort into creating a phone that resembled the look of an old mobile video game console. They also incorporated a fully integrated network board with input from a SIM card. Luckily for us, their work was all done in English. We were able to partner up with them to learn from their progress and use their product as a platform for our smartphone design.

![Figure 15: Circuitmess Ringo Phone](image)

By partnering up with them, we intend to review their design, solder all of the components together, and identify weak points that can be patched or improved upon. We were given special access to their schematics and code to help with our process.
 Hardware

One of our main goals for this project is to improve on the initial design of Circuitmess’s Ringo Smartphone by recreating our own printed circuit board that integrates all the various components and modules of the phone. Manufacturing our own PCB would allow us to add additional components (i.e. sensors, camera) to the schematic, improve cosmetics, and understand the fundamentals of the smartphone through reverse engineering.

The Circuitmess team was able to send us PDFs of their schematics of the phone which includes the main board, brain board, display board, network board, and sound board; however, they were not able to send the PCB source files and layout files due to company privacy policy. As a result, we had to recreate the schematics using the KiCad software tool, which are shown below in the following pages.

KiCad software tool had a little bit of a learning curve, but as of 3/11/20, only the main board schematic wasn’t completed yet. There are some components that will be very hard to replace/remanufacture (ie Sound IC). We are looking at ways to incorporate the pre-existing sound board onto the newly designed main board to avoid having to remanufacture the sound board.

We were also able to photograph at a good resolution all of the boards in order to follow the traces in an effort to better understand the board layout and components. Some photos are shown below.

We were also able to procure two separate kits; one that we were able to assemble and one that we are leaving unassembled. Photos of the assembled kit are shown below.
Figure 16: Brain Board Photo

Figure 17: Sound Board Photo
The team was also looking at how to minimize the vertical profile of the phone. One option to implement was to integrate the brainboard onto the main board. Another is to change the phone buttons to smaller height surface mount components (as opposed to taller through hole buttons).
Figure 19: Main Schematic
Figure 21: Display Board
Figure 22: Network Board
Figure 23: Sound Board
Software

The Ringo smartphone uses the esp 32 SoC, and we plan on also utilising this SoC in our design. The esp 32 is built by Espressif, a China based company which sells SoC’s mainly for wireless communication and IoT. The chip runs off of arduino C, and we are able to upload code using Ringo Circuitblocks. It should also be possible to upload code using the Espressif IDE and possibly from a regular Arduino IDE.

Ringo provided us with all of the source code for the phone in a github repository. Currently, we are in the process of working through the source code with a focus on the integration of new peripherals and general architecture. Ringo and Espressif both provide resources for working with the code/SoC.

Ringo Circuitblocks provides a way to graphically code new applications for the phone, such as games or general use apps (alarm, clk, etc.). It also generates the actual code for us and displays it in Circuit blocks. Unfortunately, it does not seem possible to directly code using Circuit Blocks, which limits us to the functionality that the Ringo provides. This application is good only for writing programs that work with pre-existing functions of the Ringo Smartphone, and will not be an option for programming in new peripherals.

We were able to successfully write and run a simple application that displayed a colored square and a block of text on the phone screen. This involved converting the code to a .bin file and saving it to the phone SD card. This method allows us to “permanently” upload the code to the phone without having the phone connected to a computer.

Figure 24: Circuit Blocks
CircuitBlocks is only able to upload code to the phone directly by overwriting the firmware temporarily and making the phone only able to run the uploaded application software. This prevents normal use of the phone when testing the application code. The main options for updating the firmware are the Arduino IDE and the Espressif provided software. Espressif also has a SDK that it provides to help with the ESP 32.

As mentioned previously, one of the main goals for learning the code is to be able to integrate new peripherals. One goal for the project is to add new sensors to the hardware and to be able to use them with the phone OS. In particular, we are interested in integrating GPS, a Camera, Pressure and Humidity, and a gyroscope. These components have already been ordered and are being experimented with.

![Fig 25: GPS Module](image1.png)

![Figure 26: Pressure Sensor](image2.png)
Addendum 2

Hardware

Schematic Changes

When working with the schematic provided by Ringo Circuitmess, there were some issues finding and acquiring certain parts due to lack of availability, lack of documentation on the schematic, and difficulties in manufacturing. Due to this, many parts of the hardware needed to be replaced and redesigned. This section documents some of the changes made to the Ringo Circuitmess hardware.

Resistors

The Circuitmess team was originally using resistor networks of 4 resistors for each component in their schematic. We decided to make the changes to just use single resistors with footprints of 0402 1005 metrics so it is much smaller and allows more space for layout. Additionally, many series and parallel resistors were combined.

Buttons

The original Ringo Circuitmess design involved using SPST 6mm through hole switches as its buttons. This led to a lot of issues during layout involving limited space, so we decided to make the change to SPST 3mm surface mount switches (B3FS--1002P). This freed up more space for layout so traces could go under the components.

Headphone Jack

The original headphone jack part PJ-3126-5A was replaced with a new part 35RASMT4BHNTRX. This component has the same specifications but is smaller and has better documentation.

SIM Card Holder

The original Circuitmess schematic, shown below, did not state the part number for this component, but our team concluded that this was a sim card connector. We decided to choose the part SIM7100-6-1-15-00-A which is a 7 pin surface mount micro sim card connector.
Power Stages

There were two Power Stage components on the schematic that we were not able to identify a part number for so had to redesign to the schematic specifications.

The first component was a linear regulator and the main board that took an input voltage of 3.3V and provided an output voltage of 1.8V. We chose the TLV70218DBVR, which provided an output current up to 300 mA. It needed two 100 nF (1 input and 1 output) bypass caps as supplemental components.

The second component that needed replacement was a buck converter located on the main board. This buck took the 3.7 V Lipo Battery voltage as it’s input and needed to provide a voltage between 3.4 to 4.4 V to a SIM IC. To work with the current configuration, the buck converter needed to have an internal switch and enable/disable capabilities. The sim card required 2A peak supply current.
To meet these specifications, the ADP2303ARDZ non-synchronous Step-Down regulator was chosen. It provides up to 3A load current, has an internal switch, and has enable/disable control.

All supplemental circuitry was sized according to the ADP2303ARDZ datasheet and the output voltage feedback network was set so that the output voltage was ~3.5 V.

![Figure 29: Step-Down Regulator](image)

**Audio Board**

For the audio board, and specifically the I2C audio amplifier, the issue we came across was that the IC was becoming obsolete, and it used a 9 pin BGA package that would be difficult for us to manufacture and solder to the board. Initially, we attempted to quickly look for replacements but had difficulty finding anything that had the same input protocols for data and control. Specifically, the original IC, the TFA9882, received audio and control settings using the I2S protocol. While the I2S audio protocol is a standard and there are many chips that use it, finding something with additional I2S control is very hard. Most of the audio amplifiers we found were using I2C control or had no control capability at all. For the current design, we decided to make the change to use a SMD connector to connect the TFA9882 to the main board as the BGA package would be difficult for manufacturing.

With the audio board being fully integrated into the main board, instead of a separate board, the voltage regulator SC6206B and the audio board’s header pins are now removed (shown below).
Future plans for the audio amplifier included adding some plug and play pins to the current mainboard to be able to hookup the previous and future versions of the soundboard. There are eight unconnected pins on the main board that are connected to the pinout provided for the original sound card. One future plan is to work with this plug and play version to design and test a new amplifier. Another improvement would be to upgrade the current mono audio to stereo.

**Additional Changes**

There were various additional changes made to the main board schematic. In order to free up space on the board, some of the many back-facing LEDs on the main-board were removed. Additionally, the speaker connector is now just a header pin connector instead of a JST pin connector, as the speaker will likely just be soldered in directly with jumper wires. A few capacitors were also added and removed for bypassing and extra space.
Final Main Board Schematic

Figure 31: Main Board Schematic
Layout

To be able to reverse engineer the board, a great deal of understanding the schematic as well as the individual behaviors of the components was needed. The initial design of the board was a 2-layer board, wherein the Brain Board, Display Board, and Audio Board were soldered directly onto the Main Board. This configuration was changed for a slimmer design, where the external boards were instead flush with the main board. This design would call for cavities where the boards would be, and have connectors to the main board be relatively close in proximity with the external board.

Figure 32: Initial Design of the PolyOne Smartphone

As previously stated, the PolyOne Smartphone team decided to utilize the PCB design software KiCAD. As of the end of the Spring 2020 quarter, the team was able to fully recreate the main board, as well as integrate the Sound Board and portions of the Display Board onto the Main Board. Once the major components were placed and agreed upon (such as buttons, connecting pins, LCD ribbon cable connector, and PCIE connector), the overall routing and placement of the components commenced.

The largest issue that was faced during the layout was to be able to route the different components to their respective destinations in a high density board. Therefore, a very efficient placement of each footprint was needed, with significant considerations towards spacing from other components (as to not box in a component by the traces) as well as positioning with respect
to the other side of the board. Most through-hole components that were provided on the main board of the original design were changed to their surface mount equivalent to be able to give more flexibility towards routing. The team also decided to reduce the number of RGB LEDs on the board to reduce occupied space. A significant feature of the board was the change from a two-layer to a four-layer board, giving a vast amount of flexibility to be able to route signals within the intermediary layers. There had to be a precise placement of through-hole vias, in which they did not interfere with a trace, or pad within any layer of the board.

Moving forward, to further improve the design would be the introduction of micro/buried vias to be able to only switch between two layers instead of puncturing directly through the board. A challenge to this could be an increased cost, as well as a much higher degree of difficulty in troubleshooting if the board did not perform as expected. Another improvement would be the complete integration of the Brain Board into the Main Board, as that would eliminate the need for the connectors as well as provide more flexibility to routing with a full rectangular board instead of an L-Shaped design. Another consideration for the future is the development of the overall software to handle the reduced number of LEDs to safeguard against the software crashing if it is looking for the now non-existent five LEDs.

As shown in Figure 33, the front side of the main board contains most user-interacting components, such as the joystick and selection/back buttons in the top of the board. Completing the design of the top of the board is the LCD ribbon cable connector, U14. This is followed up by a section of 4 buttons arranged in a horizontal manner which have the same functionality as the original 4 buttons on the Ringo design (Power, Home, and two auxiliary buttons). This is followed up with the standard cell button 3x4 grid, which includes 0-9 as well as # and *. The cell phone’s microphone, headphone jack, and SIM card holder finish out the design.

As shown in Figure 34, the back side of the main board contains most of the electrical subsystems tasked with ensuring the functionality of the phone. In the north-west side of the design is the main power subsystem. This subsystem is tasked with taking the battery voltage and stepping it down to power the rest of the subsystems of the phone. Near the upper middle of the PCB is the PCIE network card connector. This will be able to interface with the network card and essentially supply the phone with 4G capabilities. Below that are a multitude of subgroups integral to the phone’s operation. The audio subsystem of the phone lies in the middle of the board, headlined by U12 and U7. There is a 1.8V regulator tasked with powering the audio amplifier of the sound subsystem as well as the level translator, U4. The I/O bus IC, U8, headlines the button subgroup and is located at the lower middle of the board. It is tasked with interfacing with all the different buttons on the front of the board and the CPU located on the Brain Board. Rounding out the design is a small subgroup tasked with interfacing with the SIM card holder, which is located on the bottom right side of the board.
Figure 33: Major Component Footprint Layout - Front Side
Figure 35: Via and Track Routing
Figure 37: 3D View of PCB - Front Side
Figure 38: 3D View of PCB - Back Side
Future Additions to the Board

There are many things that we thought would be interesting to add to the functionality of the board. Here is a short list of some things we thought of implementing but didn’t have time to.

- Touch Screen
  - Pros: possibly less i/o due to removal of buttons, cool feature, larger screen
  - Cons: Difficulty in coding, need to rearrange hardware
- Potentiometer
  - Pros: Added functionality for smart turn on and sleep modes with motion sensing
  - Cons: more hardware
- GPS
  - Pros: Added functionality for GPS
  - Cons: more hardware
- Bluetooth
  - Pros: Bluetooth connectivity
  - Cons: Not much (some esp models have bluetooth)
- Update Power Supplies (Use miniature switcher IC that has multiple output voltages)
  - Pros: Can consolidate many of the power IC’s into one and save on board space
  - Cons: Needs to be designed
Software

The Circuitmess Ringo smartphone’s main IC is the ESP-32 Wroom chip by Espressif. It can be programmed in various ways. The ESP-32 is coded in C.

One way is to use the Circuitmess provided Circuitblocks software. It can be downloaded from their site. The Circuitblocks software is a graphical coding software that uses a Scratch-like drag and drop code style to program with. It essentially lets you build your code with drag and drop blocks, and then generates the actual C code for you. The biggest drawback about using this approach is that you can only code applications that work with the blocks provided. In addition, there are only so many buttons and features that you have access to when using their graphical coding.

The second way to program the phone was to use the method described by Espressif. This involved downloading and setting up the coding environment from the Espressif site. This method can directly program features of the ESP-32 and controls the pins themselves. To set up the environment properly, visit the Espressif website.

Repository

This section contains comments on the locations of useful documents in the PolyOne Smartphone Google Drive folder.

Main Folder - contains all of the subfolders as well as important documents and documents that do not have a subfolder.

Ringo Files - This folder contains the KiCad projects for the phone, the phone schematics, and a list of useful links to help with coding the phone and obtaining more info on the phone.

Phone Photos - Up close photos of the pre-assembled Circuitmess smart phone PCBs.

Meeting Notes - Notes taken of weekly meetings

The following folders are less important and were used for EE 460

EE 460 - Contains documents used for 2019 EE460 Class

Tear Down - Contains photos for the tear down assignment in EE 460

Solidworks Files - Holds solidworks files for EE 460 Assignment
Conclusions

This project’s original goal was to build a prototype smartphone with the main goal either being 5G or some privacy hardware implementation. Throughout the process of the senior project, the main goal of the project shifted many times as we began to realize what really went into building a smartphone.

Although the original goals were never met, there was a lot of experience gained from the trial and error involved in attempting to reverse-engineer a smartphone and implement our own designs in it. Our decision to reverse-engineer the board became our main task for the project and required verifying the schematics, finding and procuring the necessary parts, and finally designing the layout and ordering the components. This project gave us much more insight into the components and systems involved in smartphones, and also insight into the scope of undertaking such a task as building a smartphone.

Acknowledgment

We would like to acknowledge Professor Richard Murray, our senior project advisor, for helping us with the process throughout the year.
References


Source for Figure 1


Source for Figure 2 and 3


Source for Figure 4


Provides data about usage of phones in america and has multiple subcategories. Useful because we are interested in phone users and this data can help to identify our customers.


Used for definition of smartphone

Talks about the history of smartphones and major milestones. Also talks about what each generation of smartphones changed and gives insight into what the customers are looking for and how to define a foundation for a smartphone.


Source for Figure 5


Source for Figure 6


Source for Figure 7


This source provided various metrics and information and Apple Inc. one of the market competitors.


This source provides various information about the Google Pixel, a competing smartphone product. Give information about the features of the Pixel that customers may be interested in.

Information about Huawei, another competitor in the smartphone business. Used for market research


Information about another competitor's product. Goes through the many versions and talks about key features.


Information about LG, another competitor in the smartphone business. Used for market research.


Information about Samsung, another competitor in the smartphone business. Used for market research


This source provided condensed information regarding 5G compatible smartphones. It lists the year’s released (and soon to be released) models of smartphones with tech specs and consumer reasons to buy. It also provides a brief intro onto 5G as a communication network.


This source provides information on which carriers provide 5G compatible service. This is relevant to see the progress of 5G wireless communication and how far it still needs to develop from a service provider perspective until it can be mass utilized.

This source gives a deep dive onto 5G as a communication network. It dives into the intricacies that make 5G so effective as well as what distinguishes it from its predecessors (4G, 4G LTE, 3G, etc). It also provides insight into how it works from a physics and technological standpoint.


This source provided information as to 5G’s specific method of transmittal; OFDM. It describes how OFDM works and what makes it unique compared to previous methods of communication.


This source provided mainstream practices to remedy privacy concerns. This source was more utilized to show what was not a common practice, as there were no types of hardware solutions; only software solutions.


This source provides the statistics for smartphone sales from 2007 to 2018.


This source provides data on modern commercial smartphone battery sizes. This is used to showcase that the PolyOne Smartphone will have a greater battery life than the current market competitors.

This source gives the overview of how electronics are recycled, and the statistics behind electronic waste (e-waste) and the entire recycling process.


This source gives perspective to the negative aspects of the end of life cycle for electronics, and how they contribute to the toxic parts of our planet’s landfills.
Analysis of Senior Project

Project Title: PolyOne Smartphone
Students: Joshua Zalmanowitz, Christopher Lim, Gerome Cacho, Chi Nguyen

Student Signatures: ___________________        _________________        _______________       ______________

Advisor: Richard Murray        Advisor’s Initials: __________  Date:  ____________

1. Summary of Functional Requirements – The PolyOne smartphone team has sought to develop the first iteration of a fully functioning smartphone that future students can expand upon. At a minimum, we would like to have a design for a phone that can make phone calls and text messages. All designs should be ready to print at a PCB fabricator and easily reviewed by the next Sr. project team to take on this project.

2. Primary Constraints – Our team was constrained significantly by COVID-19. We were restricted access to all laboratory spaces and therefore could not do any hardware testing outside of computer simulation during spring quarter (the later stages of our project). We were also constrained by our lack of expertise of software and firmware. Future students selected to continue this project should include at least one student with significant experience in firmware or software.

3. Economic – Our project team was able to remain in budget. Our primary expenditures were on manufacturing the PCB as well as research into the original design. We bought enough parts to make two phones and bought additional microprocessors and sensors so that we could test the sensors we are adding to our design.

4. Human Capital – The project took up a significant amount of time for all four of the project members. Chris and Josh spent weeks on the sourcing and programming of sensors while Chi and Gerome were concurrently designing and laying out the printed circuit board with all the parts we require using KiCad. The component and PCB manufacturing also requires a human cost, which is passed down to us in the prices of the parts.

5. Natural Capital – The phone is a fully integrated electronic design comprised of copper traces, a rechargeable lithium battery, tin and/or lead in the solder, and more. The PCB and component manufacturing process also uses machinery that releases greenhouse gases and adds to the problem of global pollution.

6. Manufactured on a Commercial Basis – If the phone were to be manufactured in large numbers, all of the natural capital costs would be multiplied. There would be more greenhouse gas released from the PCB and component manufacturing and more natural resources used, notably copper and lithium.
7. **Environmental** – The lithium, copper, and tin and/or lead used in our product will be difficult to recycle for other products. Because our design prioritized a small and condensed package, the recyclability of the components drastically decreases.

8. **Manufacturability** – Our project relies on a complex global supply chain that provides electrical components to designers. The manufacturability of our product relies on all of our component’s availability on the open market. If we do have access to all components, the actual PCB fabrication is not incredibly complex. We purposefully spaced things out on our boards enough so that our manufacturers could have large margins of error. This helps us reduce cost and makes the job easier and faster for our manufacturers, who can guarantee a higher first pass yield of our boards.

9. **Sustainability** - The PolyOne smartphone design emphasizes a compact design with a serious focus on user privacy. We intend to design the product to last longer than some of the other more mainstream phones.

10. **Ethical** – The project’s primary focus was on user privacy, which is a methodology that stands in direct opposition to many of the currently available smartphones. We believe that user’s privacy rights will be expanded upon in the future through legislation but want to provide an option now for privacy minded consumers.

11. **Health and Safety** - The safety of our project is of upmost concern. The biggest liability is the power management system. We put special care into the design of our battery system.

12. **Social and Political** – The cultural effect of smartphones is complex. To some, it connects loved ones who are separated and to others it is a crippling addiction. Companies could take advantage of smartphone owners by taking their data. We intend to offer a privacy focused smartphone experience that puts the user in control. We believe this model will be years ahead of future privacy related legislation.

13. **Development** - The main software tool used for the project was KiCad. It is a free software that we used to design and manufacture the smartphone PCB. A large portion of the project was dedicated to learning KiCad and then using it to make the entire smartphone schematic and layout in order to get the smartphone PCB fabricated.

14. **Next Steps** -

   - **Hardware:**
     a. There are multiple modules that we are interested in adding to the smartphone in order to increase functionality. Some of them are: GPS module, temperature and pressure sensors, camera, and touch screen.
     b. There are also many things we wish to upgrade to improve functionality or to decrease component size and/or cost. In particular, we are interested in improving the power and the audio circuitry.
     c. We are also looking to improve the efficiency of the layout. This includes the possibility of introducing buried or micro vias, as well as being able to integrate the Brain Board onto the manufactured Main Board.
• Firmware:
  a. This project has mainly been focused on the hardware end due to the strengths of the original project group (all Electrical Engineers). Future steps for Firmware would be to look more into Firmware capabilities.
  b. The main chip we are using has built in bluetooth capability that could be implemented with the phone.

• Software:
  a. This project has mainly been focused on the hardware end due to the strengths of the original project group (all Electrical Engineers), but there were some advancements made in the Software area. Future steps for Software would be to look more into Software capabilities.
  b. Once future hardware is introduced into the system, software will be essential to enable the hardware’s functionality within the OS.
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