Cyber-Physical Systems and the Rise of Consumer E-Waste

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Today the average American produces 4.51 pounds of garbage per day, up 1.83 pounds from 1960 (Cho, 2020). This includes traditional waste such as uneaten food, single use plastics, and junk mail, but with the rise of technology there has been an exponential increase in an especially heinous type of waste: electronic waste. Electronic waste, or e-waste as some call it, is comprised of "electronics that are nearing the end of their useful life" and "are discarded, donated, or recycled" (United States Environmental Protection Agency, 2019). As it decomposes, e-waste can release hazardous chemicals like lead and mercury which pose unique challenges from a waste management perspective. Additionally, this growing problem is particularly difficult to control because it is often seen as the responsibility of individuals, corporations, and governments to independently manage.

In order to be able to continue producing tech products at the rate we currently are, we need to find a way to ethically and environmentally dispose of the waste. The current leading idea is to recycle and reuse materials from common products like phones and computers. This would reduce waste whose critical and precious materials are already becoming scarcer. For instance, "Americans dump phones containing over $60 million in gold and silver every year" (Voakes, 2012) along with other valuable resources. However, to ethically dispose of such waste would require cooperation between corporations, consumers, and government agencies to build a market that centralizes recyclability, shifts values around tech recycling, and supports safe and economical tech recycling methods. Essentially, it requires all the actors to play their part, but currently there seems to be a disconnect. The key to pushing the solution forward is understanding why this social-technical system is disjointed and finding ways for these actors to work towards their common goals together.

Problem Context

This subject of this study will be the interactions between the American consumer and United States government in relation to e-waste management. At the intersection of these consumer and governmental clashes around e-waste, we find major American technology companies like Apple Inc. which will be the focus of the study. The American context was selected because the United States is home to 10 of the 20 largest technology companies in the world (measured by revenue) (Kabra, 2022). The effect of this is an increased ability for American entities to alter global technological trends and practices. American consumers have significant influence over how their technology companies approach recycling e-waste because they represent a large portion of the companies' markets. Meanwhile, American state and federal agencies have to power to create and enforce regulations with the ability to change an entire technological product for the entire world.

Apple will serve as the case study because they are currently the technology company with the highest revenue per year, and they are a United States-based corporation with wide international involvements and impact. Apple has manufacturing facilities and dedicated consumer bases all over the world. Given their sprawl and influence, they have the ability to incorporate e-waste management throughout their entire product lifecycle and set an example for other technology companies. To try to find a solution for the problem of e-waste, looking to Apple's current practices and areas of improvement might shine some light on the situation.

STS Theory and Framework

Actor-Network Theory and the Socio-Technical Triangle framework will be used to understand the main issues surrounding e-waste management and to identify pain points in the system that could be resolved. Actor-Network Theory is the idea that two or more elements in a

system interact and have influence on one another either actively or passively. The Socio-Technical Triangle framework is the system that exists between consumers, governments/organizations, and corporations. In conjunction, Actor-Network Theory and the Socio-Technical Triangle framework can be used to explain how the relationships between consumers, governments, and corporations surrounding a particular technological issue are not fixed and stagnant but ever changing – bent and morphed by the other actors in the system.

Waste management and recycling is a multifaceted issue that involves all of these entities providing an appropriate system to apply Actor-Network Theory and the Socio-Technical Triangle framework in order to determine the greatest impacts on the behaviors of the relationships within the system. Corporations could be influenced by consumer values or their own desire to save money. Consumers could be swayed by their perceptions or needs. Governments might be motivated by revenue, an ability to regain control over corporations, or public outcry. The goal is to determine which factors have the greatest impact and if any actor in the network currently has more control.

Barriers to Consumer Participation

According to a study conducted by the Carton Council of North America "94% of Americans claim to support recycling and 74% think that it should be a top priority, but only about 35% actually recycle" (Carton Council, 2018). This represents all recycling, a small fraction of which is e-waste. However, some of the problems associated with decreased participation in ethically disposing of e-waste can be tracked to more general recycling issues on an organizational level.

The most cited reason that many Americans do not recycle is a "lack of convenient access" (Morgan, 2021). As of last year, 94% of Americans lived in an area with some recycling

program (Morgan, 2021), but due to the nature of waste management in the United States, often handled on an extremely local level, these programs can vary drastically based on location. This leads to more work on the consumer side and results in less participation in recycling. Of the 94% of Americans living in an area with a recycling program, 30% have only curbside collection, 21% have only drop-off systems, and 43% have access to both (Desilver, 2016). From here each of these recycling collection methods can be implemented in a number of ways. Curbside recycling could be "single-stream" a method in which all the recyclables go into one bin for collection, or it could involve distinct receptacles for paper, plastic, and metal. Drop-off recycling could all occur at the same location or it could be spread across a city. In addition to these options, not every recyclable is treated equally. Some services only collect certain materials. Many do not take glass and there are often only particular types of plastic that get collected. This can vary from neighborhood to neighborhood in some places. In many cases, all of these differences make it more difficult for consumers to keep track and participate. The simplest option is disposing of waste in the trash.

With regard to e-waste, this lack of access found in general recycling applies to a greater degree. Unlike traditionally recycled materials, technology recycling does not have separated categories, e.g. plastic, paper, glass, that the consumer is responsible for managing within the home. However, e-waste recycling programs are much less common than traditional recycling. These come in the most common forms of local government sponsored drives and larger corporate collections.

Government

E-waste recycling programs organized by local governments are typically drop-off. Typically, these are special event days that only happen a few times a year where the locality

will be available to collect e-waste. Most programs will collect any e-waste ranging from as small as a phone charging cord to as large as a home printer and some will have separate collections for larger e-waste like appliances (refrigerators, washing machines, etc.). However, it is not as simple as bringing the waste to the designated location, discarding, and proceeding about the day.

For example, in Charlottesville, Virginia, there is only one day for residents to drop off e-waste during 2022. A special event is being held for six hours on Saturday September 17th this year (Rivanna Authorities, 2022). Anyone who wishes to recycle their e-waste must scour available sources be able to find the information themselves. The waste management center has a calendar of events, but the e-waste event is nowhere to be found. The event brochure was only accessible by selecting specific keywords thought related sites. Additionally, participants must be available during this time and register for the event at least a week in advance in order to drop off their materials (Rivanna Authorities, 2022). What is more, the drop off site is only accessible by car. These factors filter out people who might participate but cannot because they miss the registration date, are unavailable during the small window of time of the event, or do not have access to a vehicle that will take them to an event.

People are very socially motivated and this extends to behaviors around recycling. In 1990 researchers at Arizona State University, Robert Cialdini and Raymond Reno, and Pennsylvania State University, Carl Kallgren, conducted a study on normative conduct around reducing littering to determine if there was a link between social norms and individual littering patterns. Subjects were exposed to the sight of an individual disposing of a flier on the ground. Half witnessed the littering in a clean parking lot, and the other half witnessed the littering in an already littered parking lot. Then the same flier was left on the subject's car. Only 6% of subjects

littered in the clean lot, while 54% continued to litter in the already littered one (Cialdini, Reno, & Kallgren, 1990). In both cases, the subjects watched someone discard the flier with the only difference being the current state of the lot. The researchers, therefore, concluded that the broader normalcy of littering based on the state of the parking lot had an impact on the individuals' decisions to litter themselves (Cialdini et al., 1990).

A correlation can be drawn between the example of the poor e-waste recycling options in Charlottesville, Virginia and the Study conducted by Cialdini et al. If a few residents of Charlottesville are unable to participate in e-waste recycling, then a normalcy develops in the city, then even fewer residents will seek out responsible recycling methods. In this sense, the Charlottesville e-waste problem is detrimental to improving the issue, and it is, sadly, an all-too common example of how e-waste management programs are implemented throughout the United States. By minimizing when and how residents can dispose of their technology waste, local governments are drastically limiting individual participation and communicating to citizens that the proper recycling of e-waste is not an important issue to care about, further decreasing the number of people willing to participate.

Apple and Sustainability

Apple has one of the largest trade-in programs in the country that began in 2013 as a way to drive more traffic through Apple stores (Gruman, 2013). With the grown of ecommerce, brick and mortar is no longer central to keeping customers buying their Apple products directly through the company, yet they still Apple still has its trade-in program in place. In fact, since its onset, Apple's trade-in program has expanded extensively to include all of its stores as well as a mail-in option. This is because Apple has found a way to tap into a new market: reusability.

Already having its trade-in program in place, Apple decided it could expand its products and its image as a corporation. Previously, the trade-in program was to incentivize customers to come into the store to get exposed to the entire product line by getting rid of their outdated devices and get money towards a new one (Gruman, 2013). At that time, old iPhones in good enough condition to resell were the only trade-in components getting reused while many of the rest ended up in landfills. But since 2018, they have been recycling parts from all devices using their state-of-the-art disassembling robot, Daisy, a 33 foot long, five-armed robot that can disassemble devices at a speed of 200 devices per hour (Martin & Sherr, 2019). She is able to carefully pick and sort hundreds of the devices' delicate components saving Apple millions of dollars per year on precious metals and critical hardware. As a result of its recycling practices, Apple "diverted 39,000 metric tons of e-waste from landfills in 2020" (Apple Inc, Environment, Policy & Social Initiatives, 2021, p. 45).

After success with this element of its business, Apple recently once again expanded its company on the sustainability front. In 2021, Apple released its end of the year environmental progress report where it made a commitment to recyclable and renewable manufacturing in addition to what it has already done with trade-in and disassembling programs. There are plans that to improve disassembling with a new robot, Dave, that will be able to extract larger intact components of phones and watches (Apple Inc, Environment, Policy & Social Initiatives, 2021). In the document, Apple also detailed plans to remove toxic materials like mercury and lead from new designs (Apple Inc, Environment, Policy & Social Initiatives, 2021) to make it safer for humans to disassemble products alongside both robots and reduce the hazard caused to the environment by products that do make it to landfills. Finally, the report laid out plans for Apple to fund small business research and development in the realm of aluminum production. The idea

is to work to create an alternative aluminum alloy that is more durable during the products consumer lifecycle, but can easily be removed and reused without changing its properties.

All of these advancements help Apple become a more sustainable brand that is working towards a cleaner future by creating products that can be used and disposed of safely. Though, it is not necessarily an entirely altruistic endeavor. Despite investing billions of dollars in these programs (over $4.7 billion just this year) (Apple Inc, Environment, Policy & Social Initiatives, 2021), they are recouping billions by avoiding having to procure increasingly precious raw materials and having to manufacture new components for future production. Going deeper, these sustainability initiatives set them ahead of the pack of similar technology companies. As we have previously seen, almost 75% of Americans believe that recycling is an issue that should have a high priority (Carton Council, 2018), so by adopting these practices Apple is aligning itself with this large majority of consumers. This gives them the ability to potentially gain new buyers that are more motivated to purchase brands that centralizes eco-friendly goals.

This new commitment to sustainability, specifically cleaner and greener design and production is a sound move for Apple going forward financially and socially. Throughout its tenure as a company, Apple has been known as a brand with a dedicated customer base, so leaning into a new more sustainable image can only serve to strengthen that community bond. It is this sense of community belonging that unites users around the “blue bubble” and compels customers to stand in line for days waiting for the new iPhone. However, that same dedication does not seem to shown to this other aspect of the company. In 2021, Apple sold 239 million units in iPhones alone (Adorno, 2022). About 5% of those that were discarded were resold by the consumer and only about 30% were traded-in through Apple (AppleInsider, 2021). This is a higher rate than that of Android users who sell independently at a rate of 5% and trade-in at a

rate of 10% (AppleInsider, 2021), but it is not enough to create the product landscape that Apple has designed in their 2021 Environmental Progress Report. Apple wants its customers to recycle their products but the customers' close following has not extended to supporting the trade-in program to the expected degree.

Consumer

Outside the context of wider social norms, sometimes people do not think that things are worth recycling. In a study by the Alberta School of Business, individuals' decisions to recycle certain items over others were significantly influenced by how much the item was deformed (Trudel & Argo, 2013). For example, whole sheets of paper and aluminum cans were more often recycled than small scraps of paper and crushed cans, respectively, even when presented in a greater volume (Trudel & Argo, 2013). This phenomenon was attributed to the participants' perceptions of these items' usefulness. People can imagine the new life of large pieces of paper and uncrushed cans after recycling because they still hold their original, unused forms and can therefore be useful in the future, but people have a more difficult time imagining the usefulness of paper scraps or crushed cans.

According to Argo, the lead researcher on the study, "[Coca-Cola] ran a campaign shortly after [the] first paper on the topic [was published] showing a crushed can and emphasizing it was still recyclable" (Prisco, 2017). There is no direct evidence to determine if this increased the number of Coca-Cola cans that we recycled by consumers. However, Argo believed "educating consumers through promotional materials as well as highlighting identity would increase recycling" (Prisco, 2017) The overt visuals of recyclable cans could combat individuals' opposing perceptions of what is acceptable to recycle and the emphasis on belonging to a larger

group of Coca-Cola consumers would help reinforce the idea that recycling is a crucial social norm to conform to in order to fit within the group.

Based on the evidence provided by Trudel and Argo, it is plausible to conclude that the deformity fallacy could be a major contributing factor to the low trade in rate of Apple products. Since people are less likely to recycle items that are not in their original form, trade-in programs that focus on reusing unwanted devices may be effective. The low rate of trade-ins could be attributed to devices that are beyond the point of repair. It is easy to damage electronic devices to the degree that purchasing a new one is more valuable than repairing the defective one. Screens can crack, devices get wet, and batteries eventually die. Once the devices can no longer be used by the consumer, they might not realize that the products can still be useful.

Corporate and Government Solutions

Citizen engagement is at the center of this issue. Because the problem is worldwide and part of our everyday lives, it requires communities to work together to tackle the issue. In order for citizens to participate, they need to be able to access disposal facilities. More institutional cooperation between localities and wider regulation (either state or federal) to standardize recycling implementation could reduce the barrier to participation for many people to utilize programs already in place. Standardization of practices would reduce the number of people who would already like to recycle but do not because they find it inaccessible and confusing. To increase available programs localities could partner with smaller local e-waste managers or larger corporations like Apple. Governments could subsidize smaller companies to provide additional collection closer to typically inaccessible populations. Larger corporations like Apple could work to create more community-oriented collection sites nearby highly trafficked areas similar to Amazon drop boxes but for e-waste. Both of these solutions require vast time and

financial investments. In the interim, the solution proposed by Argo to increase advertising about waste management options could be used to increase consumer participation in governmental and corporate e-waste recycling programs.

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