E-waste Tracker

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by

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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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ABSTRACT

Electronic waste trends have been accelerating since the late 20th century due to the mass production of consumer technology. Society lacks methods to get people involved in sustainable recycling practices or educate people about properly disposing of e-waste. Technology manufacturers purposefully limit the lifespan of electronics to force customers to purchase new devices. These old devices are often disposed of using methods that are harmful to the environment and surrounding communities.

Without a tool that provides information about what can be done with electronics as they get old, or what happens to those electronics once disposed of, there is no incentive to change current e-waste trends. This project aims to propose a new application which would allow consumers to enter information about their device, and provide feedback on the best course of action. Consumers could also track their recycled devices through its chain of custody to ensure it is recycled properly. By providing easily accessible information to consumers the lifespan of electronics can be increased, while electronics recyclers would be incentivized to dispose of e-waste properly.

1 Introduction

This project was focused on the design of a tool that would allow consumers and businesses to track electronics that they have passed on to recyclers. The idea behind the project was inspired by working with my father at his electronics recycling business, along with research conducted for my sociotechnical research paper. After the business started, it quickly became clear that there was a lack of recycling providers who could properly dispose of old electronics. Companies frequently upgrade to new generations of electronics and do not know what to do with the old devices once retired. Security concerns make it difficult for them to just throw these devices away. It would also reflect poorly on these companies if they were found to be harming the environment by disposing of electronics in unsustainable ways. This results in stockpiles of old electronics accumulating in storage rooms, with IT managers who have no idea what to do with all the devices. Individuals face a similar problem to businesses. They are often concerned about the effect on the environment that improper disposal will have. Old devices have their important data that could be used in malicious ways if in the wrong hands. People have more important responsibilities that need to be taken care of. Disposing of old electronics that they paid hundreds of dollars for is usually the last thing they want to spend their time doing. This leads people to keep their old electronics off to the side without any knowledge of how to get rid of them.

1.1 Current Methods

Most businesses and individuals reach a point where they can no longer hold on to these old goods. They attempt to secure their data by taking out their hard drives or smashing their device with a hammer. This often leads to old devices being taken to a landfill where there is no charge for disposal [1]. Despite being harmful to the environment, the fatigue of holding on to these devices or realizing that safe disposal costs money outweighs the environmental damage. Studies on e-waste disposal show that a very large majority of it ends up in landfills. If these groups do not bring their devices directly to a landfill, they will often find the cheapest and most convenient recycling provider. These providers end up disposing of the electronics through unsustainable methods anyway, which is what allows them to charge so little in the first place. Their practices often involve shipping e-waste to developing countries, where it is disposed of in harmful ways to both workers and the environment [2].

On the other hand, quality recycling providers market their services and sometimes connect with businesses and individuals who want to dispose of their devices properly. These recyclers provide secure methods of disposal that protect the customer's data, while disposing of the goods in an environmentally safe way [3]. Common practices involve scanning the serial numbers of devices they are recycling, allowing them to provide the customer with evidence of what they are responsible for. Businesses keep

an inventory of their devices for security and monetary purposes, which allows them to match their record to what the recycler provides. This is usually the end of communication with the customer, as the devices are then the responsibility of the recycler. The devices are resold if they are in good condition, broken down for the valuable materials inside, or sent to a specialized disposal facility if they contain dangerous materials.

1.2 Problems with Current Methods

Businesses and consumers face few barriers to disposing of their electronics improperly. Once data is secured, the easiest option is to go with the cheapest recycling provider or simply throw devices away in a landfill. This is obviously detrimental to the environment and will only increase as people upgrade their electronics at a faster rate. If these groups do try to recycle their devices, they have no way to know if the recycling providers follow sustainable practices or not. Since the relationship ends once the recycler acquires custody of the devices, these electronics end up wherever the recycler sees fit to send them. In some cases this means they will be disposed of properly, in other cases they will be sent to other countries or thrown in a landfill to save money.

The methods used by recyclers take a long time to return feedback to the customer disposing of goods. Scanning the information on devices is a tedious process in itself, but then this data must be compared to what the customer provided to ensure it is correct. This often has to be done manually by someone working for the recycler, as there is no good system to compare this data currently. On top of this, the recycler usually has to process all of the goods they receive from a customer before providing feedback. This means that hundreds of devices must be scanned and compared to given records before returning a report to the client. Such inefficient practices cause another barrier to the proper disposal of electronics.

2 Background

Electronics recyclers utilize technologies such as Zebra scanners that allow them to scan information from devices that they receive. These scanners are then able to upload the data to whatever system the recycler uses to keep track of its data [4, 5]. Businesses often use much simpler scanners, that simply loads a scanned entry into an excel sheet or similar system, to keep track of their devices.

3 Related Work

There are currently no popular systems built specifically for the purpose of allowing consumers to track their recycled electronics through the end-of-life chain of custody. Electronics recyclers use systems such as Salesforce. This allows them to keep track of customers, store data specific to a certain job that is acquired from a scanner, and keep track of the profits that each kind of electronic being recycled has brought in. These systems only provide the customer with an initial report about the recycler acquiring disposed of devices, and not one regarding the entire end of life process.

The Basel Action Network has utilized GPS tracking devices to study where recycled electronics are actually sent [6]. These efforts have implicated electronics recyclers who lie about their practices to customers. They have developed a system, Earth Eye, which allows businesses to use these GPS devices and track where their recycled electronics end up [7]. This system does not provide documented tracking of all electronics that a company recycles. It only provides a limited amount of GPS trackers to businesses each year, meaning they can only track one device per GPS tool they receive. The effort and cost of such a system is greater than what an individual with electronics to recycle would be willing to put in.

4 CS 3240

Since this project did not require an actual implementation, I felt that CS 3240 would be a good elective to incorporate to help meet the requirements. The main efforts of the project were dedicated to deciding how the software development process would be conducted, and identifying the different design decisions that would be part of that process.

4.1 Stakeholder Identification

There are three main stakeholders that requirements would need to be obtained from to develop this system. These stakeholders include electronics recyclers, businesses with electronics to recycle, and individuals with electronics to recycle.

Electronics recyclers would benefit from this system as it would provide an automated interface that compares their inventory to the inventory provided by the customer, which then sends quick feedback to the customer. The elicitation techniques that would be most useful for this group would be interviews with different recycling providers, observing how these providers currently process electronics, and examining artifacts regarding how data is stored and the information that is provided to customers. Interview questions could include:

1. Approximately how much e-waste do you process each year?
2. How many customers currently employ your service?
3. In what ways could your current methods of device tracking be improved?
4. How long does it typically take from device collection to providing the customer with feedback?
5. In what format is the data uploaded from scanners stored in?

Businesses with electronics to recycle would benefit from this system by receiving updates from the recycler much faster. Another benefit would include being provided with clear documentation about the environmentally friendly supply chain that their recycling provider uses. The elicitation techniques that would be most useful for this group would be interviews with the IT managers at different companies, observing the methods that these companies use in order to keep track of their inventory, and examining artifacts to determine what kind of documentation they require to show that safe and secure disposal methods were used. Interview questions could include:

1. What are your current methods of disposal for old electronics no longer in use?
2. How often does your business upgrade to new generations of electronics?
3. How long does it take recycling providers to return feedback after picking up devices?
4. In what format do you keep track of the devices in your inventory?
5. Does your company have a way of confirming that the recycler disposes of devices in a sustainable manner?

Finally, individuals with electronics to recycle would benefit from increased transparency in the recycling process. They would also benefit from a simple interface that makes it easy to connect with recyclers, while being able to keep track of their devices and ensure they are disposed of securely. The elicitation techniques that would be most useful for this group would include observing the current methods that individuals use to dispose of devices, and questionnaires which are able to acquire feedback from a large number of individuals. The questionnaire could include:

1. How do you currently dispose of old electronics? (Recycling, Landfill, Resale, No Method)
2. How often do you upgrade electronics? (Semiannually, Annually, Biannually, Other)
3. Do you conduct research about recycling providers before hiring them? (Yes or No)
4. Would a system that keeps track of what happens to your recycled electronics interest you? (Yes, No, Maybe)
5. Does there need to be more transparency in the recycling process for you to get involved? (Yes, No, Don't Care)

Once initial requirements are obtained from these participants, it would also be beneficial to employ rapid prototyping. This would allow the development team to see how potential users try to interact with the system, and whether those users find certain features useful or not. The information obtained from the prototyping would give users a better idea of the envisioned system, and allow them to provide more in-depth feedback regarding what they would expect out of the application.

This system would derive its income from the recyclers and businesses that utilize it. Recyclers would be incentivized to pay for the system because it has the ability to replace the current methods of device tracking that they use. It would also provide faster response time to customers and eliminate the burden of having to manually compare scanned inventory to inventory provided by the customer. The application would promote recycling and attract new customers looking to dispose of devices. Businesses would be incentivized to pay for this system because it would provide them with a medium to host information about their electronics inventory. They would be provided with automated reports on the supply chain that their devices went through once recycled. This would ensure that their data was disposed of and secured in the way that the recycler said it would be, while also allowing them to obtain proof for stakeholders and the government that their company uses sustainable methods of recycling.

4.2 System Design

This system would primarily be a web application. The main focus of designing the system layout was to adhere to the MVC pattern of dividing resource management. In order to meet this pattern, I decided that MySQL would be the best option to manage the models of the application, and that PHP would work best as the controller. These decisions were based off my experience interfacing with MySQL through PHP, which was done extensively in Database Systems.

After deciding that these would make up the model and controller aspects, I looked into different frameworks that could make up the view portion of the system. After

researching different possibilities, I decided that the Angular framework would work best with the other components [8]. It seemed that Angular was a good framework for separating the interactions with the database from the frontend aspect of my application. Since I plan to have three different kinds of users, Angular provided a framework that would allow me to create components that could be reused while still allowing for different functionalities. Angular provides a simple way to communicate with any RESTful API through the use of the HttpClient service class. It is also a useful framework for creating an aesthetically pleasing and professional design.

My REST API architecture would be built with PHP. At the endpoints referenced by my Angular frontend, I would have a PHP file that would process requests that are passed from the frontend. In my academic work I have found that PHP provides easily manageable interactions with the database. These files would allow client side events to trigger different reactions from the database. This is important as most of the main functionality involves users uploading data, which then updates and searches through the database.

Both the frontend and backend aspect of the application would be hosted on AWS instances. The database could be hosted on AWS through the Relational Database Service they provide [9]. By using these cloud services, the application could easily be scaled as more businesses and recyclers join the system. Recyclers and businesses often have a large number of devices to keep track of, and using the cloud would allow this to happen without having to manage my own physical systems. This would also prevent the users of the application from having to save a large amount of data on their own physical machines. Once data is uploaded from client-side devices, it will be saved by in the system by the cloud separate from any physical devices owned by the user.

4.2.1 System Functionalities. The system would consist of three different types of users, corresponding to the different stakeholders. IT managers at companies with electronics to recycle could create “Business” accounts, and recycling providers would create “Recycler” accounts. These types of accounts would enter information regarding their business and create an administrator user. This administrator account would have complete access to the corresponding business’s records, and would be able to designate other users as employees who would only be able to upload data. All specific users would make accounts using an email and password, or they could log in using Google OAuth. Employers could then add their employees’ accounts to a list that gives them access to upload data to their system. Individuals with electronics to recycle would have an account that is not connected to any recycler or business, and would only allow them to upload one item at a time.

Businesses often dispose of electronics in cycles, where batches of devices are recycled at a time. Administrators of a business account would be able to create a “Job” for each batch of electronics. Information about devices waiting to be recycled would be uploaded to the system in standard data transfer format, for example xls or csv, with the specific job closing when those devices are picked up by a recycler. Once a job is closed, the business would be prompted to identify what recycler retrieved the devices. As the recycler processes the devices and uploads information in a similar format on their side of the system, the business will be able to see the progress that is being made on the job the recycler is working on. The system will provide the business with updates when their electronics are acquired by the recycler, completely processed, passed onto another location, and when data on the number of devices that are resold, broken down for parts, or sent to a hazardous waste facility is ready. Once the electronics recycler is done processing, the business will be provided with a formal report on the chain of custody of the devices as well as how they were recycled.

Recyclers have multiple jobs for multiple different companies that they need to be continually updating. Once electronics for a job are retrieved, they will confirm on their end that the devices were acquired. As they process devices, they will upload the device information to the specific job of the company whose goods they are recycling. This information will then be matched with the inventory provided by the customer, and will provide the customer with real time percentages regarding how much of the job has been processed. The customer will be told once all of the goods have been processed, and where they are being sent next. Workers will update the system telling whether a device is resold, broken down for parts, or sent to a hazardous waste processor. Once all of the devices are recycled, the recycler will close the job and the customer will automatically be provided with a formal report.

Individuals would manually input a devices serial number and model information to a form. They would then be able to bring the device to a recycler, and tell the system where the device was brought. This device would then have information regarding its disposal connected to it, allowing the user to click on the device and see its chain of custody. It would be similar to the way the system works for businesses, but individuals usually only recycle one or two items at a time, allowing information to be directly tied to a single device. When a customer’s device is processed, moved, and disposed of they will be updated. After its disposal, the customer would have clear information on

where the device traveled during its end-of-life processing, and how it was disposed of in a sustainable way.

5 Database Systems

The other elective I decided to incorporate into this project was Database Systems. This class provided extensive work with relational databases that fit well with this project. I focused my efforts for this part of the project on overall database design and the identifying different commands that would be needed to alter the database correctly.

In order to articulate the design of the database, I elected to create an ER diagram. This seemed to be the most efficient way to show how the different entities that make up the database connect to each other. My ER diagram consists of seven different entities. These entities include recycler, recycler administrator, business, business administrator, individuals, devices, and jobs. Primary keys for each entity are labeled with "PK". Upon first use of the system, businesses and recyclers are created along with a respective administrator. In the ER diagram, the business administrator entity exhibits total participation and a one-to-one relationship, "manages", with the business entity, because both of these entities are dependent on the creation of the other. The same relationship is shown for the recycler administrator and recycler entities.

Business and recycler entities both connect to the job entity. Businesses create and add their inventory to a job, while recyclers process a certain job once they acquire it. The job entity has attributes isAcquired, which is set when a recycler acquires the devices, isProcessed, which is set when the recycler has processed all of the job's devices, and location, which is multi-valued and updated when the job's electronics move facilities. A device entity has a many to one relationship to jobs, showing that one job "is made up of" many devices. Devices also have an attribute isProcessed, which is set to true when that individual device has been uploaded by the recycler, and an attribute disposal method, which is updated at the last stage of recycling detailing how the device was recycled. Finally, the individual entity is connected to devices through an "inputs" relationship. It is a one-to-many relationship, since one individual can input multiple electronic devices into the system. This entity refers to both individuals with electronics to recycle, and employees of businesses and recyclers. Employees are identified through the multi-valued attributes connected to the business and recycler entities, and these individuals would have permissions to upload lists of devices for their employers. Individuals who are not employees would input one device to be recycled at a time, with an individual job being created for that device.

The database would utilize stored procedures upon upload of data to automatically update related information. Business and recycler administrators will be automatically added to the individual entity table when created. When a business inputs devices into the device table, the database will also update the "is a part of" relationship table to add the devices to a corresponding job. As recyclers scan and upload devices, the isProcessed field will be set to true on those devices. A query will then be called to calculate the total number of items in that job and the number of items processes, which will then be used to calculate a percentage processed value to be displayed to the customer. Once that value reaches 100 percent, the isProcessed value for the entire job will be set to true, and the customer will be notified. Location values are added to multi-valued attribute under job by the recycler, and the customers view will be updated to see where their devices are being sent. Finally, as the recycler finalizes disposal of a job's devices, the disposal method attribute will be updated for each device and the customer will be updated with automatic statistics regarding how their devices were recycled.

6 System Testing

As with any software system, the application would require unit test as the different functionalities are being coded to be sure they work as expected. These tests aim to catch smaller defects in specific functions before integration tests are run, with the hope of saving time and money later on. Unit tests would include equivalence, boundary, and exception tests for functionalities like creating the different kinds of users, trying the different methods of uploading data for each user, adding employees, or updating the recycling progress on a certain device or job. As unit tests confirm that these functionalities work on their own, successfully tested functions can then be observed working together.

This is when integration testing can be conducted to ensure that as parts of the system are combined, they work together as expected. The application involves many interconnected parts that are dependent on changes from other parts of the system. Tests for this part would need to include updating a recycler's jobs when a business or individual indicates that they used that recycler, if an upload of data from a recycler successfully marks electronics as processed and provides the customer with updates, if updates are given to the customer on the current stage of the recycling process. These integration tests, along with unit tests, would need to be conducted on any new code being added to the current build before it could be deployed.

Once integration testing is completed, system testing would take place to test the functionality of the application as a

whole. These tests would look at the system from the perspective of the different users, and work through the different interactions with the system those users could have. After completing system tests, the application could utilize beta testing by allowing a small number of possible users access. This type of testing can help ensure that the application was built in a useful way for normal users. It also allows changes to be made before acceptance testing if the tests reveal that some aspect of the system does not meet expected requirements. Finally, acceptance testing would be conducted with stakeholders to receive confirmation that the system meets the expected functional and non-functional requirements.

7 Needed Resources

Risk analysis is an important part of the development cycle, and especially in a system where large amounts of sensitive data is being kept track of. The polar chart used for determining whether a software project should be agile or plan driven was a good starting point for me to analyze potential risks. In the case of this system, a software defect resulting in the halt of the system could delay processing of electronics for all types of users. This has the potential to be very expensive to anyone using the system, and could be detrimental to their business if an issue persists. The system also holds sensitive information on devices being recycled, including their current location and how they were disposed of. If malicious actors were to acquire this information, they could find recycled devices and attempt to recover information, or steal from recyclers and hold peoples' information for a ransom. Such situations place the criticality of failure just before that of loss of life. Since this is a fourth year thesis project, it could be assumed that many of the devs are also recently graduated individuals with little experience.

Getting requirements right the first time in this project would be important, as designing a system that does not fit the needs of the users would be detrimental to the project. It would also mean that requirements should change very little throughout the development process. Knowing this, the software development process would likely take 3-4 months. This would include 3-4 weeks of requirements elicitation, as there are many different entities in each group of stakeholders that must provide requirements. The next 2-2.5 months would be spent working on the development of the system. Although tests would be conducted as new features are added, the last .5-1 month of the process would be spent on quality assurance and further testing to make sure that all aspects of the system work correctly. These considerations lead to an estimate of about 30 devs being needed to complete this system. As all the other aspects of the system lean largely towards a plan driven model, a large number of devs would be needed. This would allow practices such as paired programming to mitigate risk, and if one dev fails to meet their expectations there are plenty of team members to make up for it. Work could be evenly distributed in a structured way that ensures the system is completed on time.

6 Conclusion

This system was designed to give people a sense of involvement in the recycling process. It is meant to unify different aspects of the recycling industry, bringing together commercial and individual recycling with real time updates on what is being done with recycled goods. A transparent interface between the customer and recycler will promote more people to dispose of their goods properly. Not only would the tool save time and money for recyclers and businesses, but it would also be a step towards easing the burden on the environment caused by e-waste. There needs to be more efforts and proposed solutions on how to get people interested in disposing of their electronics properly. The exponential trend of increasing e-waste ending up in harmful places will not go away on its own.

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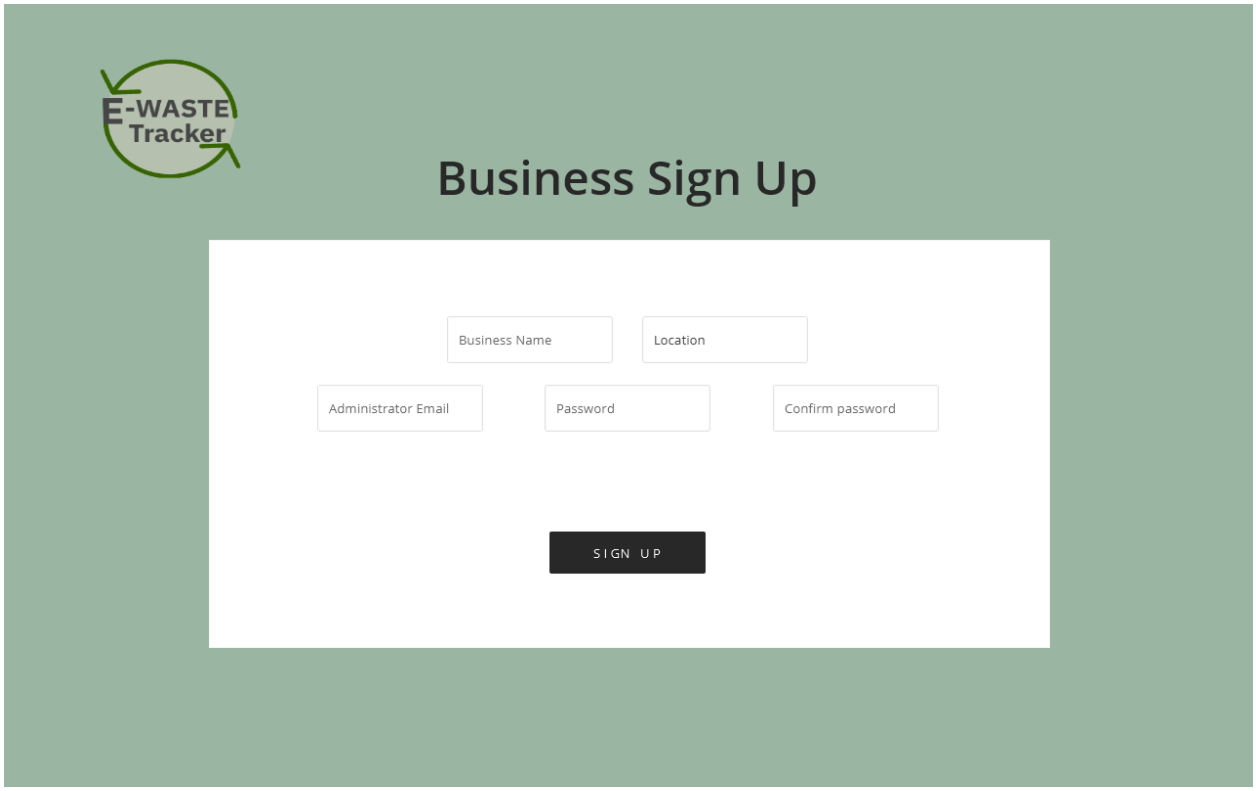
Mock Screens:




E-WASTE Tracker
Add Devices
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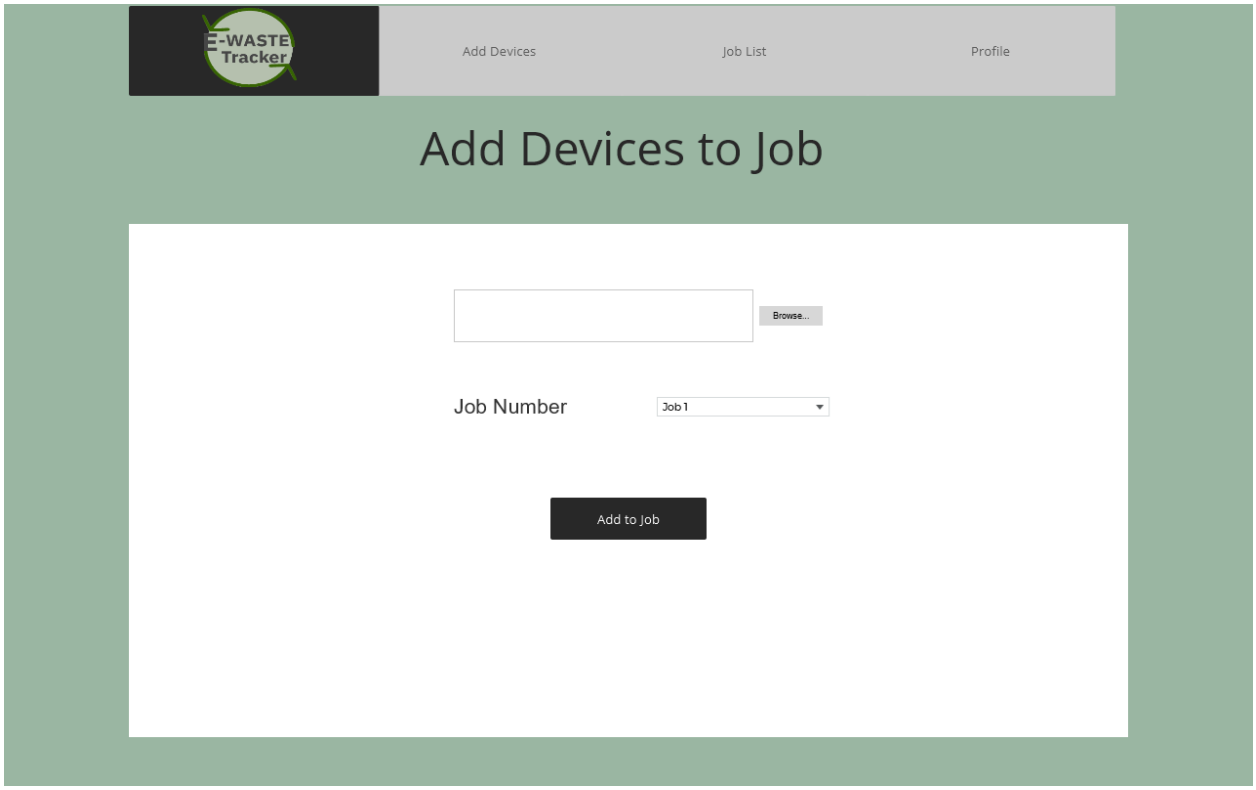
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Job 1
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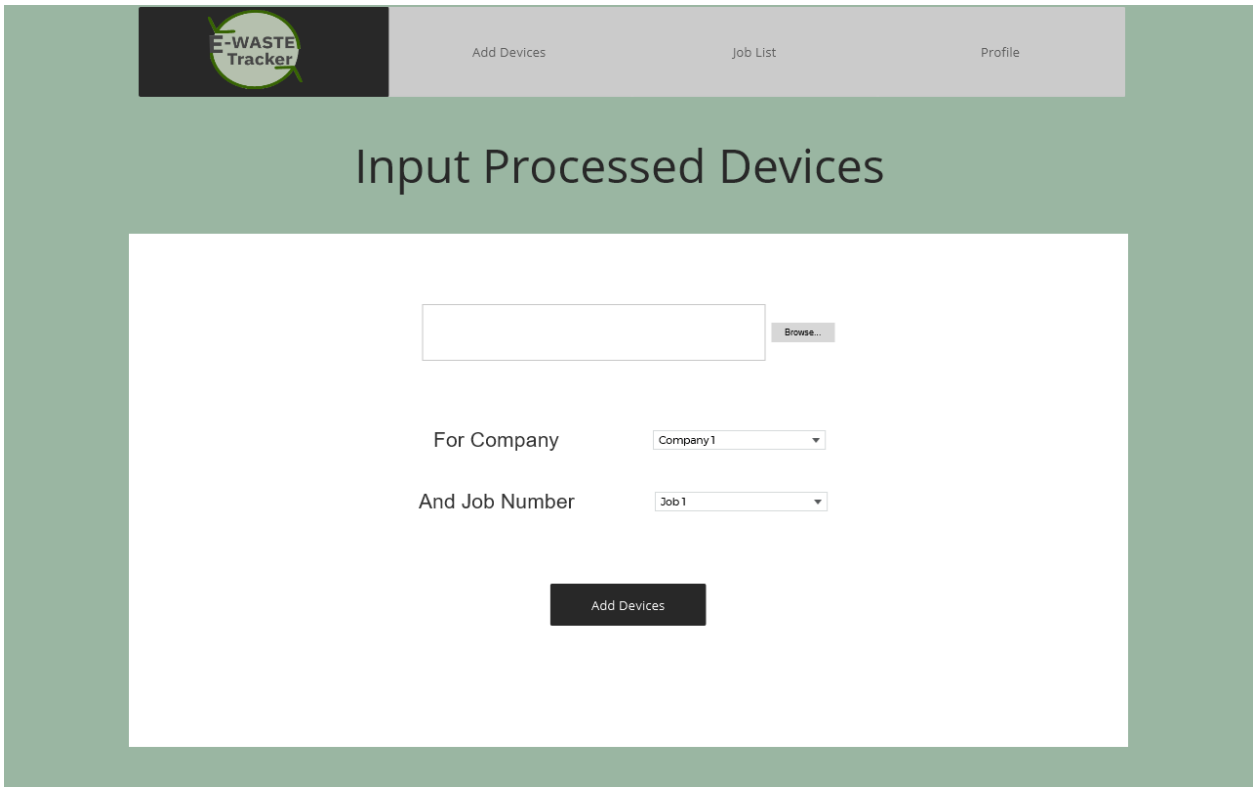
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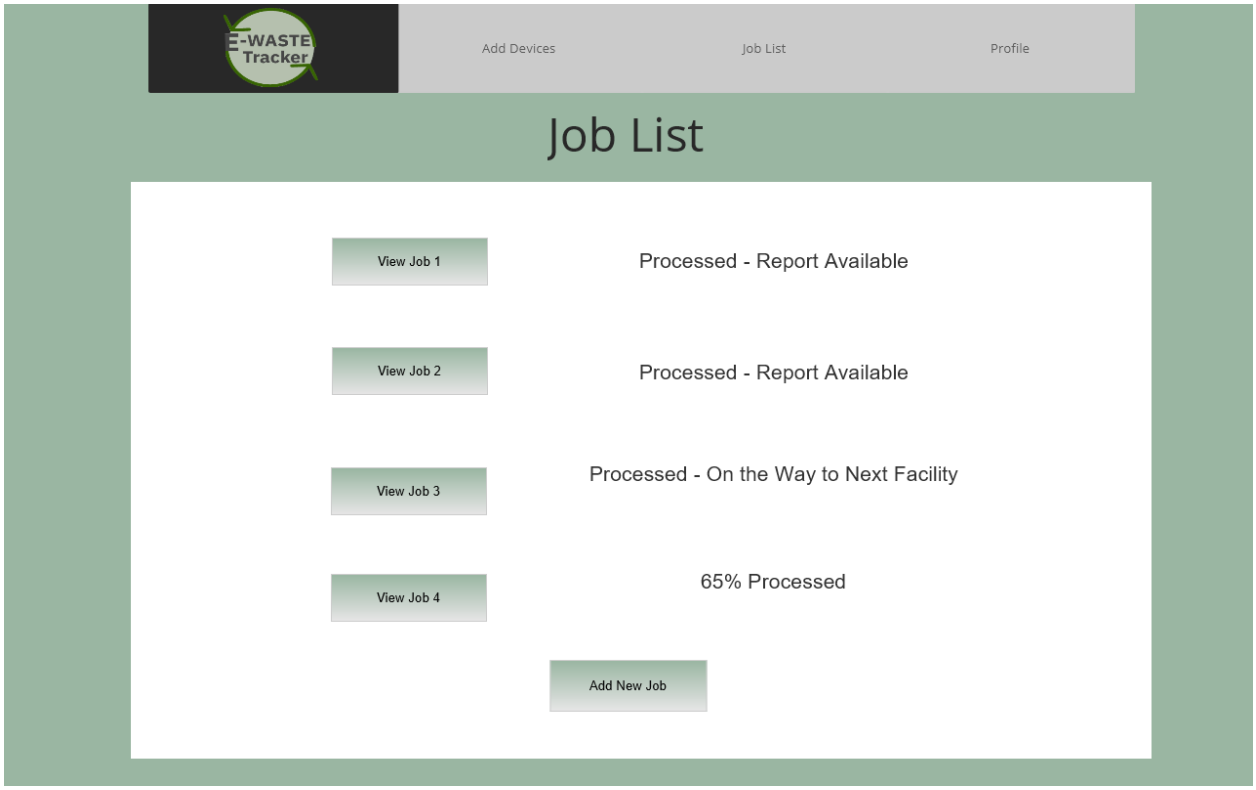
E-WASTE Tracker
Add Devices
Job List
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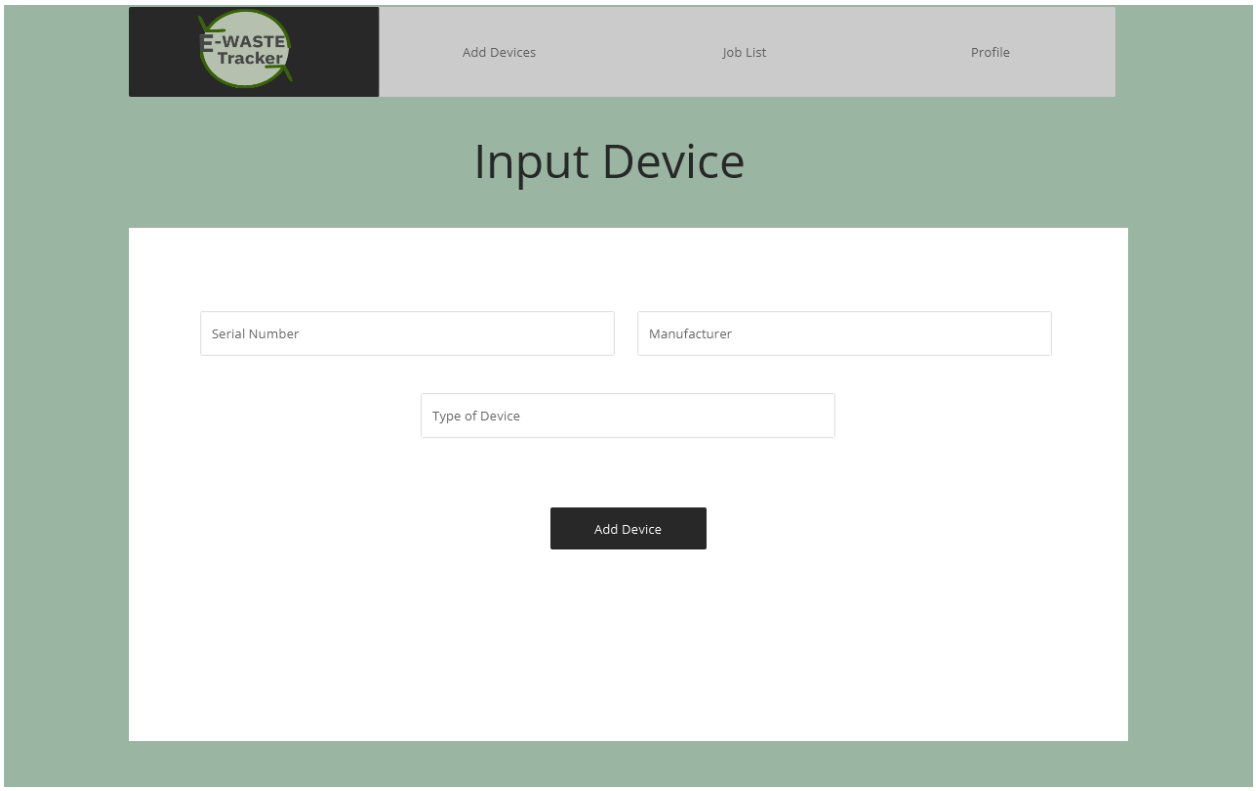
Job List
View Job 1
Processed - Report Available
View Job 2
Processed - Report Available
View Job 3
Processed - On the Way to Next Facility
View Job 4
65% Processed
Add New Job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Tracker
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Profile
Input Device
Serial Number
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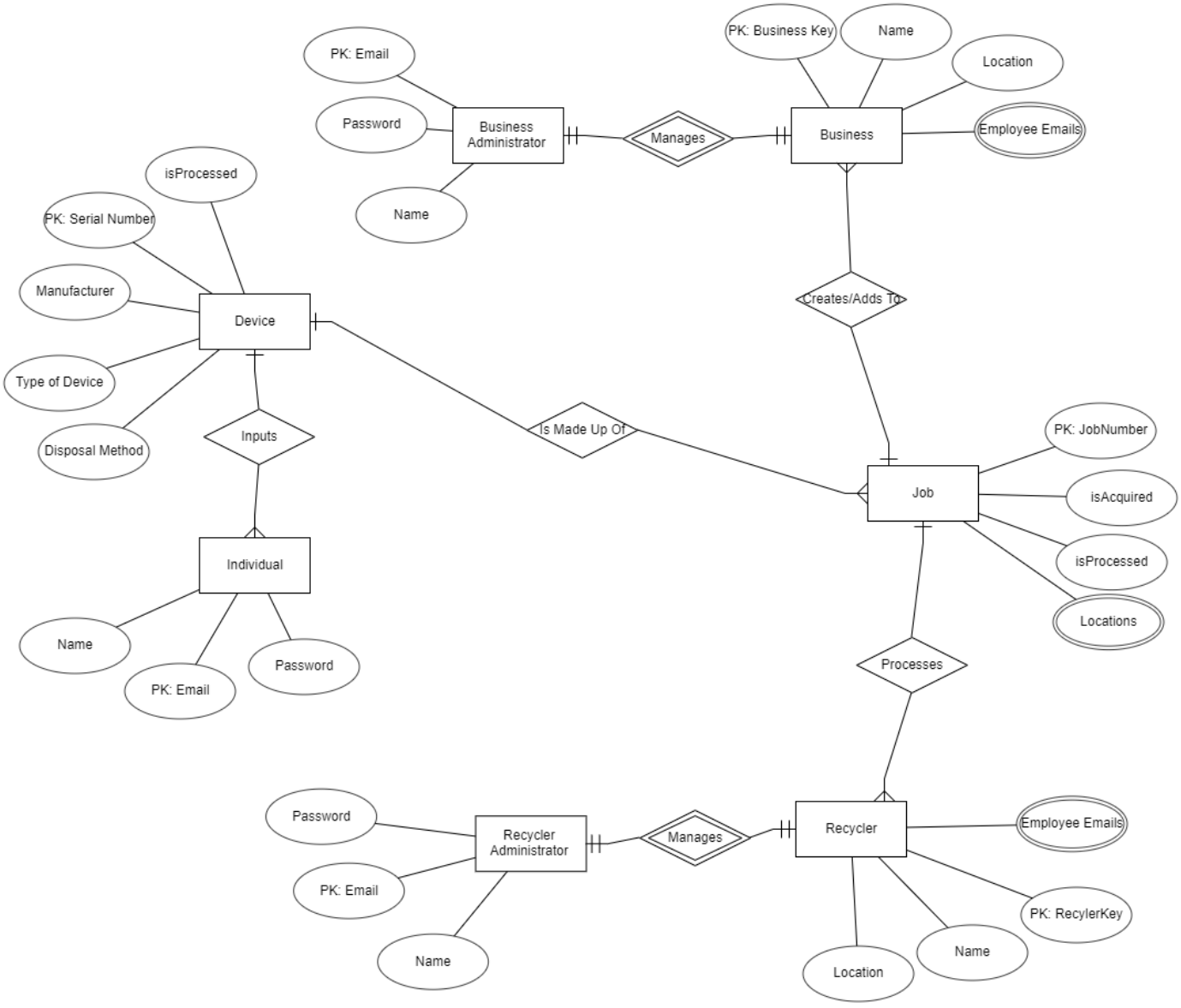
Type of Device
Add Device

ER Diagram:


PK: Email
Password
Business Administrator
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PK: Business Key
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Employee Emails
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PK: Serial Number
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