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HOMETRACKER: A HOUSEHOLD INFORMATION FEEDBACK SYSTEM FOR FOOD/ENERGY/WATER METABOLISM

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By

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Table of Contents

List of figures

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List of abbreviations

API: Application Program Interface

FAFH: Food Away from Home

FAH: Food at Home

FEW: Food, Energy and Water

FEWCON: Food, Energy and Water Conscious

GHG: Global Greenhouse Gas

INFEWS: Innovations at the Nexus of Food, Energy and Water Systems

HomeTracker: Household Metabolism Tracker

HTTP: Hypertext Transfer Protocol

LCA: Life Cycle Assessment

MVP: Minimum Viable Product

NSF: National Science Foundation

OCR: Optical Character Recognition

SDH: Sustainability Development House

SE: Socioeconomic

TCP: Technology, Climate and Policy

USEEIO: United States Environmentally-Extended Input-Output

Abstract

The Food, Energy and Water Conscious (FEWCON) project seeks to understand how food, energy and water (FEW) as independent resources within households are connected. In the main study of the project, intervention messages that link household FEW consumption to equivalent climate consequences are pushed to the households. The goal of the FEWCON study is to determine potential intervention messages that influence household FEW consumption behavior.

A key component of the FEWCON study is a web application named HomeTracker (Household Metabolism Tracker) which collects FEW consumption data within households, then uses this data to select consumption-specific feedback to the homeowners. To collect FEW household data, both manual and automated techniques are integrated into the HomeTracker. The overall feedback system is semi-automated, with protocols established for both HomeTracker and the participants.

The goals of the HomeTracker as a software system arewere to accurately capture FEW data, to be consistent across participants of the FEWCON study, and to minimize the burden on the participants while maintaining integrity of the overall study. The FEWCON team spans six institutions and five collaborators and includes individuals with a wide range of backgrounds: environmental engineering and modeling, climate and ecosystem science, social and behavioral economics policy, and software engineering. With such a diverse team of geographically distributed stakeholders, there were challenges in the decision making process of developing HomeTracker. Through iterative design and attention to the stakeholders, HomeTracker has accomplished its goals.

This report details the research and development process for creating HomeTracker. It begins by introducing the FEWCON project and the associated household study. The HomeTracker development project is then outlined. This is followed with the details regarding the design decisions made throughout the development of HomeTracker. The report concludes by discussing the next steps that should be taken to finalize the HomeTracker for the FEWCON study.

1 Food, Energy and Water Conscious Project Overview

FEWCON (Food/Energy/Water Conscious)[1] is an interdisciplinary project that spans six institutions, five collaborators and 14 investigators. The heart of the FEWCON project is a planned intervention study that will collect data on household-level *food, energy and water (FEW)* consumption in order to identify potential interventions that promote FEW conservation (Watkins et al., 2016).

1.1 Motivation

As the global population increases, the demand for FEW resources also increases. There is ample opportunity for U.S. households to take action to reduce overall FEW consumption (Shwom and Lorenzen, 2012). Estimates predict that voluntary actions taken by U.S. households could reduce overall greenhouse gas emissions by 7.4% and reduce household direct emissions by 20% (Dietz et al., 2009). There are numerous challenges associated with reducing consumption of FEW resources, including lack of consumer awareness and disconnect between consumption choices and impacts (Arthur, 1989).

Generic "go green" campaigns, such as the three R's (reduce, reuse and recycle), tend to have positive outcomes but not the lasting effects needed to address problems related to FEW over-consumption (Shwom and Lorenzen, 2012). The FEWCON project is specifically looking at the interactions of the FEW Nexus within a sample of U.S. households. With the FEW data collected from this sample of households, these consumers will have access to new information regarding the direct and indirect effects of household-level FEW consumption allowing the FEWCON team to determine the most effective means of promoting FEW conservation (Di Donato et al., 2015).

1.2 Timeline

FEWCON consists of three research thrusts occurring over a five year project period: 1) life cycle impacts of household FEW consumption, 2) socioeconomic feedbacks and interactions and 3) technology, policy and climate scenarios development. The tasks for life cycle impacts of household FEW consumption focus on mapping the direct and indirect impacts of each FEW resource to begin development of the life cycle assessment (LCA) model. Socioeconomic feedbacks and interactions research consists of gathering preliminary information to finalize plans to execute the FEWCON intervention study. A role playing game developed by FEWCON project participants at Arizona State University is being used to gain insight regarding potential conservation behaviors (Agusdinata, et al., 2019). A national survey is also being sent out to test which intervention messages lead to the most significant changes in behavioral intentions

[1] The Food, Energy and Water Conscious (FEWCON) project is funded by the National Science Foundation (NSF) Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) initiative under grant number 1639342.

towards FEW consumption (Agusdinata, et al., 2019). The final task of the second research thrust is to perform the year-long planned FEWCON intervention study. The data collected from the second research thrust will be used to inform the final research thrust to look at how information can affect household consumption behavior.

1.3 The FEW Nexus

The FEWCON project is analyzing FEW data as a nexus, meaning how they are interconnected. This FEW nexus entails modeling a total impact of each FEW resource based off of the direct and indirect impacts. The total impact being developed for FEWCON is a total greenhouse gas (GHG) emission. For example, if the direct input for food is a cheeseburger, the direct impact is the cheeseburger itself. The indirect impacts of the cheeseburger include the land and water used, transportation costs, and energy used to prepare the cheeseburger ("The Carbon Footprint of a Cheeseburger", 2017). All these direct and indirect impacts have associated GHG emission values which can be calculated to come up with a total GHG impact of a cheeseburger. Other means of analyzing the FEW nexus are being discussed, such as a model that includes both direct and indirect impacts as GHG and water impacts to create a total impact, but have not been decided at this time.

2 Food, Energy and Water Conscious Planned Study

2.1 Study Details

A key component to the FEWCON project is the intervention study planned to begin in September 2019 and continue for 12 months. The study will be conducted across 200-250 households located in two Chicago, Illinois suburbs: Prairie Crossing and Gurnee. During the study period, food, energy, natural gas and water consumption data will be collected from each participating household. In order to collect this data, participating households will use a web application called *HomeTracker* (*Ho*usehold *Me*tabolism *Tracker*). This collected data will be aggregated into an overall household FEW consumption score, to provide periodic feedback to participating households via the HomeTracker.

In addition to periodic feedback, participating households will receive intermittent intervention messages through the HomeTracker. The types of interventions that will be tested include 1) information about FEW consumption for each FEW sector, 2) information regarding the impact of consumption across all three FEW sectors, 3) social comparison information, 4) information on how to reduce consumption in each area and 5) information on the larger impacts of FEW consumption in terms of climate change. The study is tracking the effect that the intervention messages have on household FEW consumption behavior. Pre- and post-study surveys will be conducted across participating households along with pre- and post-study in-depth interviews across a subsample of participating households.

2.2 Study Timeline

Food data tracking differs from tracking energy, water and natural gas data. Energy, water and natural gas will be tracked over the entire 12 month study period. There will be a pre-intervention food study where food data will be collected for two weeks in the beginning of the study. This initial food data will be analyzed and an intervention message will then be pushed to participating households. A post-intervention food study will follow after the release of the food-related intervention message with another two week period of collecting food data. The pre-intervention food study data and the post-intervention food study data will then be compared to see the effects of the intervention message.

2.3 Project Design Team

In order for a project of the scope of FEWCON to be successful, multiple areas of expertise are required. Thus, the FEWCON project is multidisciplinary, consisting of four sub-teams:

- LCA: performing a FEW consumption based environmental impact assessment to develop an LCA model for the FEWCON project. The developed LCA model

exemplifies the direct and indirect impacts of FEW resource usage which can then be converted into equivalent climate consequences.

- Socioeconomic (SE): researching and testing potential interventions to determine which intervention method should be used throughout the planned FEWCON study.
- Technology, climate and policy scenarios (TCP): looking at climate patterns of the planned study region in Illinois to assist in the development of FEW related policymaking.
- Cyber enabled data collection (CS): developing HomeTracker, the web application being used as a feedback loop during the planned FEWCON study.

All four sub-teams work closely together to improve the overall understanding of potential ways to reduce household FEW consumption, display the total FEW impacts and educate on FEW-related policymaking (Watkins, et. al, 2016).

3 HomeTracker

3.1 Overview

The HomeTracker is the tool that participants of the study will access to input household FEW data, view detailed and aggregated FEW consumption data, view the intervention messages and participate in study surveys. The HomeTracker allows scientists to view the collected FEW data across all participating households. The process of designing the HomeTracker and collecting FEW data regarding each variable is described in the following subsections.

3.2 Project Goals

Like any software project, HomeTracker has multiple goals. One goal is ensuring the FEW data collected is accurate. The proper information needs to be collected from participants and stored in a format that maintains the accuracy of the data for further data analysis. Discussions were held on deciding what information should be available to the participants on the HomeTracker and how it should be displayed.

HomeTracker wants to maintain the integrity of the planned FEWCON study. The HomeTracker developers did not want the design decisions made to lead to unintended influences in participant behavior. For example, at the beginning of the project the FEWCON researchers were debating whether or not participants should be able to view the FEW data that they had uploaded to HomeTracker. The team had to determine if displaying previous participant FEW consumption to the participants would impact consumption behavior. It was decided that giving participants access to their own FEW information does not influence behavior. In this instance, participants would be able to view FEW data they upload to HomeTracker in HomeTracker.

Another goal of HomeTracker is to be consistent across all participants. All participants of the planned FEWCON study would be interacting with HomeTracker to perform the tasks of uploading and viewing data, viewing intervention messages and taking surveys. With all participants performing these tasks in HomeTracker, HomeTracker acts as a common denominator throughout the planned study. The developers of HomeTracker wanted to ensure all participants have the same experience using HomeTracker. The goal of keeping the display and functionality constant across all participants furthers the goal of maintaining the integrity of the study.

The final goal of HomeTracker is to minimize the burden on the participants. The participants would be actively using HomeTracker during the study, inputting FEW data, taking surveys and viewing FEW consumption feedback and intervention messages. The amount of time and effort required of the participants to perform these tasks should be minimized while maximizing the accuracy of the data collected.

From these goals, it was decided that focusing on creating a minimum viable product (MVP) would further the successful development of HomeTracker. A MVP regarding software is the smallest system you can create that meets all the requirements to deliver customer value (Ries, 2017). Focusing on a MVP aligns with an Agile development process (Ries, 2017). Agile development has a Manifesto that emphasizes focus on valuing individuals and interactions, working software, customer collaboration and responding to change (Beedle, et al., 2001). With many of the design details of HomeTracker constantly evolving, focusing on a MVP allowed for changes to the HomeTracker to easily be made.

3.3 Framework

The initial plans for HomeTracker were for it be a mobile app. People often have their phone with them and so having HomeTracker be a mobile app would allow it to be easily accessible. This ease of access would assist in the usability of inputting FEW data into HomeTracker. Providing feedback on FEW consumption and pushing intervention messages would also be streamlined by utilizing notifications.

With limited mobile app development knowledge, a process that allowed for parallel iOS and Android app development was needed. PhoneGap was the first framework tested but was found to have too many limitations. PhoneGap itself is a development framework and a mobile app that acts as a server (“PhoneGap”, 2016). In order to use apps developed in PhoneGap, they need to be ran through the PhoneGap app itself; not as a standalone app. The developed app can be accessed through the PhoneGap mobile app using a server number provided when the project is compiled (“PhoneGap”, 2016). This framework may be ideal for a personal project but not a project as extensive as HomeTracker.

Fuse was another cross-platform frameworks researched. Fuse is built on a language called Uno, which is similar to C#, which is then compiled into C++ (“Fuse Open”, 2018). The “hikr tutorial” was completed in Fuse where it proved to be a promising framework (“Fuse Open, 2018). Fuse front-end development is completed in UX, a markup language similar to XML (“Fuse Open”, 2018). Fuse allows for integration of JavaScript functions into the front end (“Fuse Open”, 2018). The learning curve required to use Fuse as a development framework seemed to be low.

As the details of the HomeTracker were worked out, it was found a mobile app was insufficient. The concern of the limitations of having HomeTracker as a mobile app were particularly voiced by the researchers developing the food tracking process. The information that the HomeTracker would be capturing and displaying was not ideal for the screen size available on a phone. The framework of the HomeTracker was then changed to a web app.

Having experience using Grails from Michigan Tech's CS4760 course, Grails was the framework selected for developing the HomeTracker. Grails is Java-based and allows for easy flow-of-data between the front end and back end. The HomeTracker also needed to be developed as a REST web service due to the interactions required to collect the necessary data for the FEWCON study. The HomeTracker being a REST web service allows other software applications to access the HomeTracker to provide information. HomeTracker is deployed on a Tomcat server maintained by Michigan Technological University Information Technology. A Mariadb database was included within the Tomcat server for HomeTracker.

3.4 Tracking Household Member Information

The number of household members in each participating household of the FEWCON study is being collected in addition to the household members' first names. Using household size is one way FEW usage can be compared from household to household. On the HomeTracker, a form is in place which prompts the participant to enter in the number of members in their household. A table is then generated with the same number of rows as household members entered to prompt the participant to enter in the household members' first names. This data can then be submitted to the HomeTracker and later edited by the participant, if needed.

The reason for saving the household members' first names is to aid in complete food data collection. Further explanation of this reasoning can be found in the following subsection "Food Away From Home Data Collection" under the "Tracking Food" section.

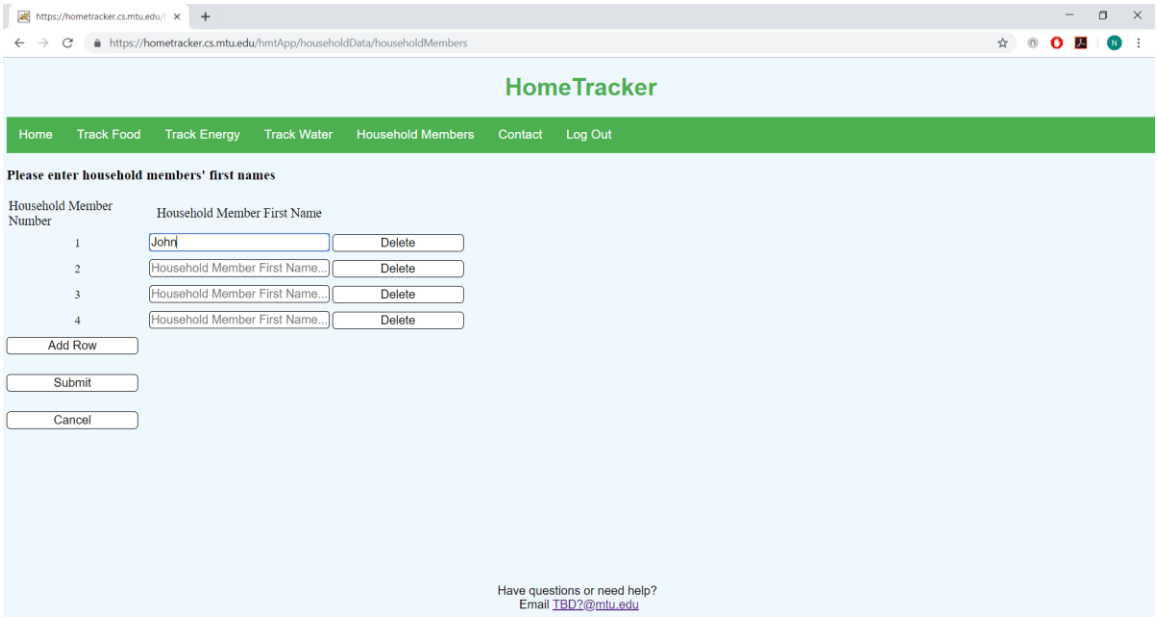

Figure 3.4.1. Screen capture of Household Member form in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

3.5 Tracking Food

The process of collecting food data proved to be unique and the most challenging aspect of the data collection regarding resource use in the home. At the beginning of the HomeTracker project, it was unknown what it meant to track food data within a household. The decision was made to have the direct household input for food be the dollar (USD) amount of an associated food category. The associated food categories come from the United States Environmentally-Extended Input-Output (USEEIO) model (Yang, et al., 2017). Each USSEIO category has an associated value that takes into account the direct and indirect impacts of growing, producing and transporting the purchased food item (Yang, et al., 2017). The USEEIO category values are then be applied in the LCA model along with its corresponding total dollar amount to provide a total food GHG emission impact.

With a dollar amount being the direct input for food data, the collection of receipts was the means decided upon to gather household food data. Each food item on the receipt is entered and categorized into the appropriate USEEIO category along with the total amount of the item to get the total GHG emission impact. For example, if a participant purchased bananas at $2.16, the USSEIO category would be “fresh fruits” and the associated dollar value would be $2.16. This category and price would be the inputs for the LCA model.

There are two broad categories of the USEEIO food categories: 1) Food at Home (FAH) and 2) Food Away from Home (FAFH). Within the FAH category, there are two use cases that could occur: 1) participants make a purchase for FAH and receive a receipt (such as going to a grocery store), or 2) participants make a purchase for FAH and do not receive a receipt (such as going to a local farmer’s market).

3.5.1 Food at Home Data Collection

3.5.1.1 Food at Home with Receipt

Knowing that participants will be collecting receipts, initial work was done researching existing optical character recognition (OCR) software. Upon initial research, it was surprisingly found that OCR receipt parsers is an active area of development. There are many competing OCR products for a variety of applications. The information needed for the FEWCON study was line-item detail of the receipts, both the item purchased and its associated price. At first, the software Taggun appeared to offer line-item detail as a parsing option of receipts. After speaking with a company representative, it was shared with us that no software existed on the market that performed receipt line-item parsing (“OCR API for Real-Time Receipt Scan”, 2018).

One of the last software that was found that appeared to offer line-item parsing detail of receipts was the application program interface (API) offered by Itemize. The form sent to

receive more information regarding the Itemize API was originally denied due to the nature of the high security data Itemize typically works with. The Chief Strategy Officer from Itemize was interested in the goal of the FEWCON project and reached out to offer support. A demo was given of the API which showed it parsing out the detail of the receipt line-by-line in a JSON response. The Itemize API documentation also showed an example response of parsed receipt line items ("Itemize API Docs", 2019). After purchasing a trial of the Itemize API and testing it, it was found that the Itemize API did not actually offer line-item detail parsing of receipts.

This left two options; one option involved writing a receipt parser specific to the needs of the FEWCON project. Since there was not an existing OCR parser that offered this service, it appeared to be a project in itself. The formatting of receipts from business to business was too inconsistent to develop a reliable receipt parser that offered line-item detail. Due to the one-year development time constraint of HomeTracker, this option did not seem feasible.

The second option was to have participants input every food purchase they made into HomeTracker manually; this is the option currently implemented in HomeTracker. Part of the manual entry process for food at home with receipt purchases is having participants upload images of their receipts. There were two unknowns with this process: 1) how participants should photograph the receipts and 2) how much detail participants would need to provide in order for the receipt items to be categorized.

To address the first unknown, we knew the receipt images needed to be of high enough quality that when the receipt image was displayed on the screen in HomeTracker, the text on the receipt could be read. This was not only to add to the usability of the HomeTracker for the participants, but more importantly for the employees who would be categorizing the purchases. As stated, one of the goals in developing the HomeTracker was to minimize participant burden. To further this goal, there are paid individuals, students at Michigan Tech, who will categorize the food purchases uploaded by participants. Having employees categorize the food items and not the participants also minimizes the introduction of categorization error. The categorization employees need to be able to read the item price from the receipt to input into the HomeTracker so that the total GHG impact can be calculated. It was found that if a participant had a long grocery receipt, the receipt would need to be broken into multiple images. An instruction page showing the process of photographing a receipt consisting of multiple images was developed into the HomeTracker.

To address the second unknown, it was discussed that the participant just uploading the receipt with metadata (the date of the purchase and the store/merchant where the food was purchased) was not enough information. The protocol to receive the necessary information for the categorization of receipt food items required participants to annotate their receipts by typing the common food name for the respective food code/abbreviation on the receipt. For example, if the receipt read "DELI TRK", the participant would enter "lunch meat" into the HomeTracker. The original idea was to have participants only

annotate items on the receipt in the HomeTracker that did not appear obvious. After collecting and analyzing different receipts, it was decided the protocol required participants to annotate every food item on the receipt. This would minimize the issues that may arise during the categorization process.

3.5.1.2 Food at Home without Receipt

The process for participants to submit FAH purchases without receipts is similar to the process of submitting a food at home purchase with a receipt. The key difference is that without a receipt, participants bypass the step of having to take a picture of the receipt uploading it to the HomeTracker. Participants have fields prompting them to enter the date of the purchase and the store/merchant of where the purchase was made. The participants are then prompted with a table consisting of fields to input the food item common name and associated item price. Once all required fields are filled in, the purchase is submitted to be later categorized by the categorization employees.

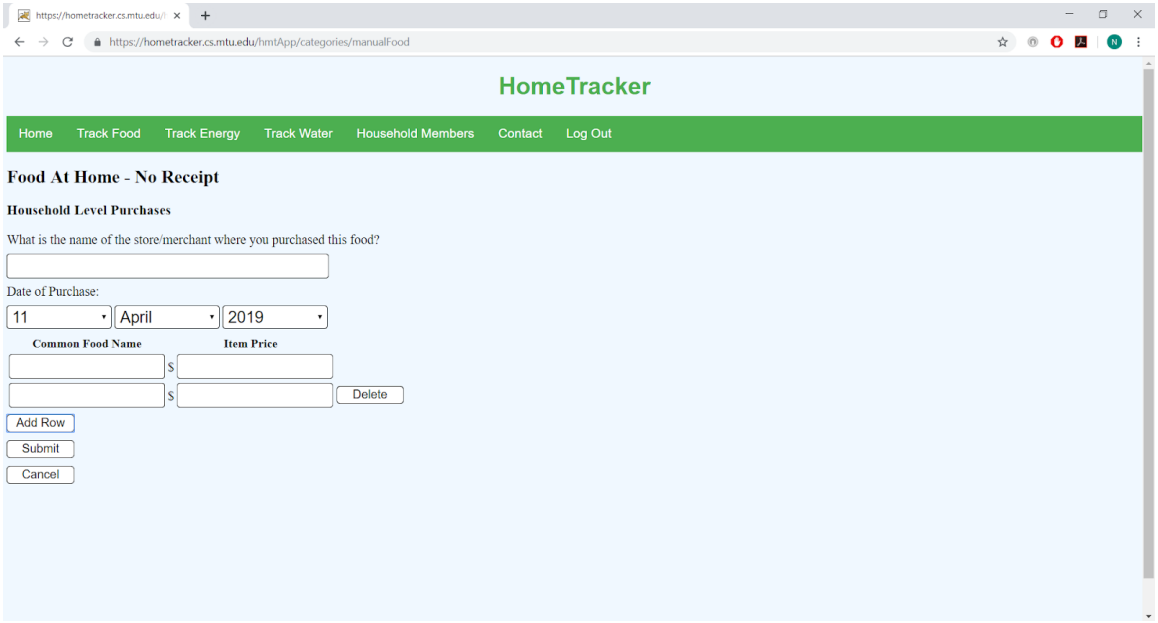

Figure 3.5.1. Screen capture of FAH no receipt form in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

3.5.1.3 Categorization Process

The categorization employees will have admin level accounts in the HomeTracker. When an employee logs in, they would see all the FAH purchases submitted by all participants of the planned study. The employees would then select one of the purchases to begin the categorization process. If the purchase being categorized had a receipt, the receipt image(s) are displayed on the screen alongside the table of annotated items and fields to be filled in. The employees can verify the common food name matched the item on the receipt images and enter in the associated price of the item as printed on the receipt. The

employees then select the appropriate category from a dropdown menu for each item following the USSEIO categories. Training and a categorization guide will be provided so that the employees know which food items belong to which categories. Once each item has a selected category and price inputted, the purchase would be submitted to be calculated for a total GHG impact.

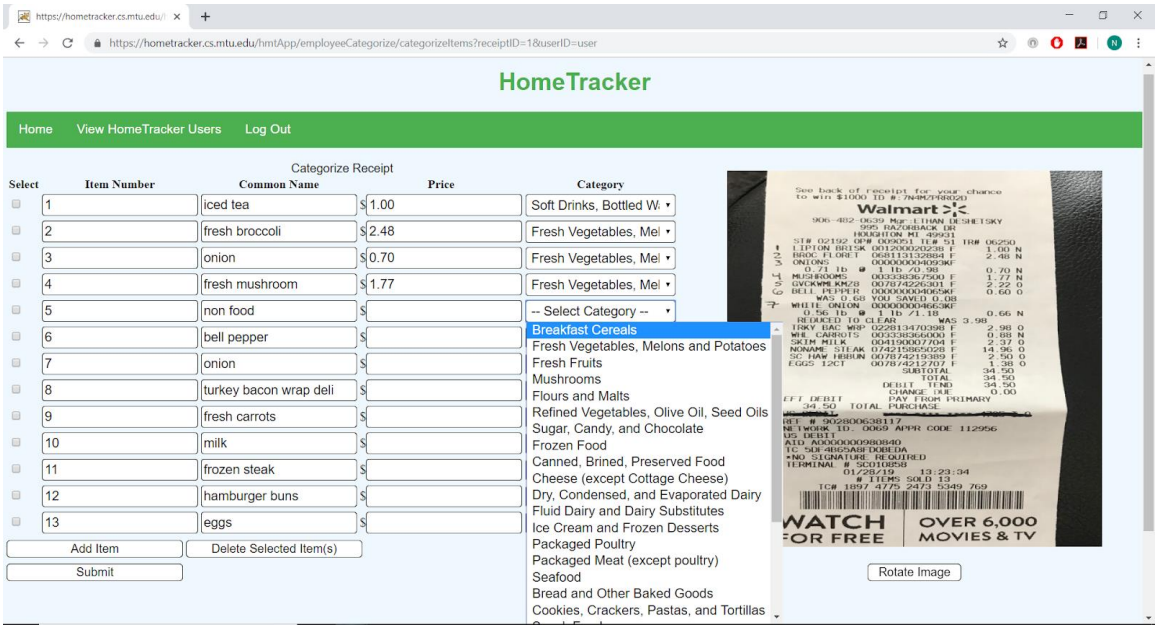

Figure 3.5.2. Screen capture of FAH with receipt categorization process in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

If the purchase being categorized did not have a receipt, the common food name and price would already be inputted and would not need to be verified. The employees would select the appropriate USSEIO category for each of the inputted food items. This purchase would then be submitted to be calculated for a total GHG impact.

There is a table in the HomeTracker database that stores associated common food names and categories. Once a food item has been categorized, the employees do not need to select the category of that food item in the future. This table allows for "pre-categorization" to occur where common food names and associated USSEIO category can be initially stored in the category database table to minimize the burden on the employees and minimize error in categorization.

3.5.2 Food Away From Home Data Collection

Following the USSEIO categories for tracking food away from home (FAFH), there are two categories: full service and limited service. Full service is defined to include food served to you at a seat by a waiter or waitress. Limited service is defined to include food that you took to your own seat or to your home or elsewhere to eat. Since the calculation of food purchased into total direct and indirect impacts only requires a USD dollar

amount and associated category, the receipt images for food away from home purchases do not need to be uploaded to the HomeTracker. The participants just enter in the total amount spent for a given date for each category in the form for food away from home on the HomeTracker. If nothing was purchased for the selected date for one of the categories, the participant leaves the field blank. The data may then be submitted to the HomeTracker.

To aid in ensuring FAFH data is not missed, the form for FAFH prompts for each household member. The first names of the household members submitted as part of household information appears on the form with input fields for "full service" and "limited service" for each household member. It is predicted that multiple household members will be eating food away from home separately. The goal with this method it to make it easier for the participants to input food away from home. Instead of having to come up with the total amount spent on either limited service or full service food for all household members combined, the amount each household member spent can be inputted. If the participant does not or has not submitted household member information to the HomeTracker, or is in a household size of one, the food away from home form only prompts for household level food away from home purchases, not all household members.

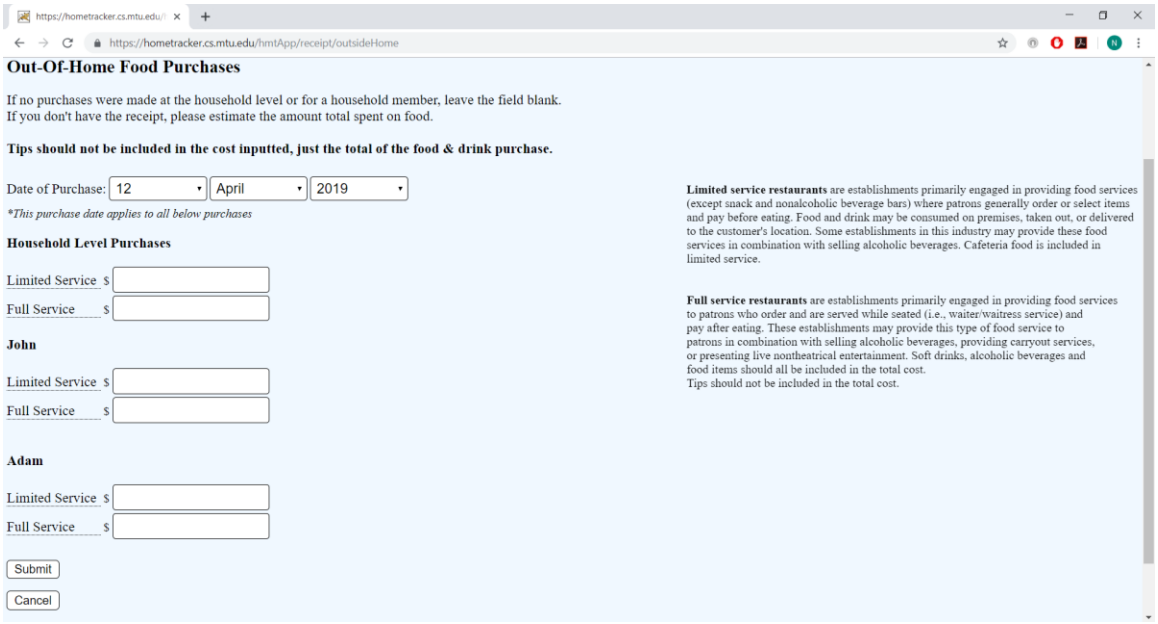

Figure 3.5.3. Screen capture of FAFH form in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

3.5.3 Preliminary Results: Food Tracking Pilot Study

The beta testing of the food tracking process consisted of 20 participants interacting with the HomeTracker over a two week period of inputting food purchases. The two week testing period proved that the HomeTracker was stable and performed as expected. One

of the post survey questions asked the participants if they would be interested in participating in a similar future study and all participants responded with either maybe or yes, suggesting promising results leading up to the planned FEWCON study.

There were two main changes made to the HomeTracker based off of user experience during the beta testing period. The login screen was updated to state that users were logging into the HomeTracker. “Forgot username” functionality was also added to the login screen. One participant had noted they entered in a FAFH purchase twice, yet they were unable to edit the purchase themselves. They had to contact the research team to have it manually removed from the database. Functionality that allows participants to view recently submitted FAFH purchases and delete them on the confirmation page upon submission was added to the HomeTracker.

A few concerns were noted when testing the categorization process. When categorizing food at home with receipt purchases, it was found some receipt images uploaded were unreadable. The way some participants took pictures of the receipts cut off the price information which is needed to complete the categorization process. The process of inputting the common name of the items on the receipts also needs to include key details, such as being frozen, canned, or fresh, to categorize the items properly. It was also found that identifying items that participants had forgotten when annotating their receipts was very challenging, if not impossible.

After the user testing period had ended, a key database issue was discovered. A couple bugs were detected in the admin features of the HomeTracker, affecting the categorization process. These bugs were fixed and the application was redeployed to the Tomcat server. Grails has many configurations, including settings for connecting to a database. One of these configurations is “dbcreate” which can take on multiple settings, including but not limited to: “create-drop”, “create”, “update” and “validate”. The “dbcreate” setting specifies how the database should be generated from the domain model within the application. Following a Grails documentation, it stated to set “dbcreate” to “none” when redeploying an app in production (Configuration, *The Grails Framework*). Having data from the trial period and not wanting to affect the database currently in use, “dbcreate” was set to “none”. This resulted in a HTTP 404 not found error when the HomeTracker link was accessed and existing data in the database had been deleted.

Not anticipating to lose the existing data, a backup of the database had not been made. Having the server and database hosted by Michigan Tech, I did not have access to many of the SQL log files and associated database files. Fortunately, a backup procedure existed within the original database framework and the data from the user testing period was able to be recovered by the Michigan Tech IT. Further reading lead to the finding that depending on the setting of “dbcreate”, an unknown existing plugin may change the setting to “drop-create”, which would drop all existing data from the database and create a new, empty database (Petrin, 2016). From this situation, time was spent determining which setting to use for “dbcreate” when redeploying the HomeTracker while in

production. A procedure was established for redeploying HomeTracker when in production to ensure a backup of existing data was in place.

3.6 Tracking Energy

In order to get a complete picture of energy consumption within households, FEWCON is tracking both electricity and natural gas usage.

3.6.1 Tracking Electricity

Wanting to automate the process of inputting electricity data, the initial plan was to use energy monitors to track electricity usage. Using energy monitors would also provide the FEWCON team with granular electricity data of each participating household. Existing energy monitors on the market were researched, including Smappee ("Analyze. Control. Save", 2019), Neurio ("Neurio Energy Monitor", 2019), Sense ("The Sense Home Energy Monitor", 2019) and Curb ("Know More. Spend Less.", 2015). One requirement of the energy monitor was for it to have an API that could be integrated into HomeTracker. At the time, Curb and Sense did not have established public APIs while both Smappee and Neurio had public APIs. Smappee and Neurio also had the ability to detect appliances in a home after installation. In order to select which energy monitor to move forward with, they had to be tested.

Michigan Tech has an ongoing project, the Sustainability Development House (SDH), which aligned with the motivation of the FEWCON project. The SDH was an ideal location to test the Smappee and Neurio monitors. After contacting Michigan Tech Facilities to install the devices into the fuse box of the SDH, installation did not go as intended. Both Smappee and Neurio need to connect to a Wi-Fi network to complete the installation process. After installation, the energy data collected can then be viewed in their respective mobile apps and/or online portal. Due to the configurations of the Michigan Tech Wi-Fi networks, neither Smappee nor Neurio were able to connect to Wi-Fi. Michigan Tech IT needed to set up a special Wi-Fi network for these devices. IT also needed the IP addresses of the devices for them to join the created network. Neurio fortunately had the IP address printed on the monitor. In order to get the IP address of Smappee, it had to be connected to a network. The Smappee device was connected to an at-home Wi-Fi network to get the IP address. It was then connected to the Michigan Tech network to be installed at the Sustainability House. Once the installation process had been completed for both Smappee and Neurio, there were issues in collecting energy data. The user manual for each device states it may take a few days before data is available to be viewed. After a month of being installed in the SDH, the mobile apps for each device were displaying unrealistically low kilowatt hour values for a home that had six students living in it.

With there being so many problems in installing the energy devices at the Sustainability House, it was decided it was best to start over. One of the Smappee devices was

attempted to be installed in the home of a Michigan Tech professor on the FEWCON project. It was found the Smappee device could not be installed in the fuse box of the home due to the age of the house. Smappee devices are engineered to work in newer homes, which proved could be a limitation during the FEWCON study. Reaching out to Smappee Support employees was also challenging as the company is based in the UK.

From the electricity monitor testing process, it was also found that an intrinsic motivation and interest needed to be present in order to make the devices work successfully. After experiencing roadblocks in getting Smappee and Neurio to work as expected, it was decided that having each participating household install an energy monitor was not going to be feasible for the study. The FEWCON team still wanted to see what would be possible with these energy monitors. A pilot study is being conducted before the planned FEWCON study with recruitment in progress to have 20 households participate. These 20 households would have the energy monitors installed in their home where the electricity data would be collected from the energy monitor over a period of time.

During the initial testing process of these energy monitors, discussion was held with the Illinois electric company, Commonwealth Edison (ComEd). ComEd is the electric utility that participants of the FEWCON study will be getting their electricity from. ComEd stated they did not have an API in place to provide the energy data the FEWCON study was looking for. ComEd directed us to GreenButton Connect ("Green Button for My Home", 2018), which gets electricity data from ComEd in 15 minute intervals. GreenButton Connect interfaces with third party providers to share the ComEd electricity data ("Green Button for My Home", 2018).

UtilityAPI is a software company that offers an API that automatically downloads bill data from electric utilities ("Utility Data Made Easy", 2019). UtilityAPI allows data to be viewed either on a daily, weekly or monthly basis and also offers the collection of historical data ("Utility Data Made Easy", 2019). It was found that UtilityAPI was a registered third party for GreenButton Connect. Upon meeting with an UtilityAPI representative, it was noted that by December 2018, UtilityAPI would be able to pull energy data from ComEd. The UtilityAPI was implemented into the HomeTracker to collect participant electricity data following the API documentation. A scientist on the FEWCON study is a resident in Illinois and a customer of ComEd. She tested the authorization process and integration of UtilityAPI into the HomeTracker.

In order for the FEWCON team to view participant electricity data through UtilityAPI, the participant need to fill out an authorization form linked on the HomeTracker. After submitting the form, the participant is redirected back to HomeTracker. About 24 hours after the form is submitted, electricity data can be viewed in HomeTracker.

3.6.2 Tracking Natural Gas

To capture complete energy data, natural gas usage of each participating household is also being collected. The natural gas utility in the Illinois area of the study had been

contacted to find out about the possibility of the HomeTracker pulling natural gas data through an established API. The natural gas utility does not have an equivalent to UtilityAPI which is being used to automate collection of electricity data. A form was created in the HomeTracker where participants can manually input their natural gas usage. The form prompts the user for the date and the natural gas use in therms. When the participants receive a natural gas bill, they will enter the information from the bill into the HomeTracker using this form.

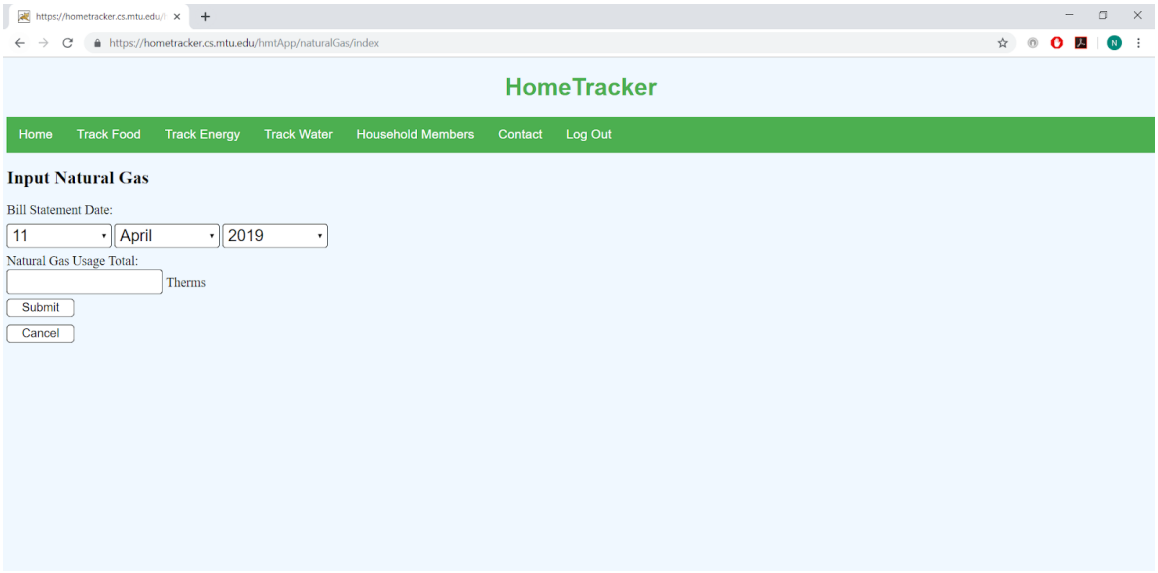

Figure 3.6.1. Screen capture of Natural Gas entry form in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

3.7 Tracking Water

In an effort to further minimize the amount of work required of participants in the FEWCON study, a means of automating the collection of water data was looked into. Discussions began with the Illinois water utility to see if they offered a means of sending their water data to an external software (the HomeTracker), either through an API or something similar. It was found the water utility did not directly offer an API to share water data. Further reading lead to Pecan Street. Pecan Street is a company that researches how technology and behavior interact to provide the insights needed to lead to a more sustainable energy and water system (“One of a Kind”, 2019). One of the devices Pecan Street offers is BluCube. BluCube collects the data from analog water meters every four seconds, stores the data in servers and allows users to access the data on internet connected devices (“Water Research”, 2019). After reaching out to Pecan Street regarding BluCube, the device was found to be quite costly. A single BluCube unit costs $665, since the FEWCON study would have between 200-250 participating households, there would be an additional monthly cellular service fee.

Due to FEWCON project budget constraints, BluCube was not able to be installed in every participating household for the planned study. Unable to find an alternative to streamline the collection of water data, it was decided participants of the FEWCON study would have to manually enter in their water usage, similar to the process of entering in natural gas data. A form was created on the HomeTracker that prompts participants to enter in the amount of water in gallons that appears on their bill statement in addition to the date. Each time a participant receives a water bill, they will have to input that information into the HomeTracker.

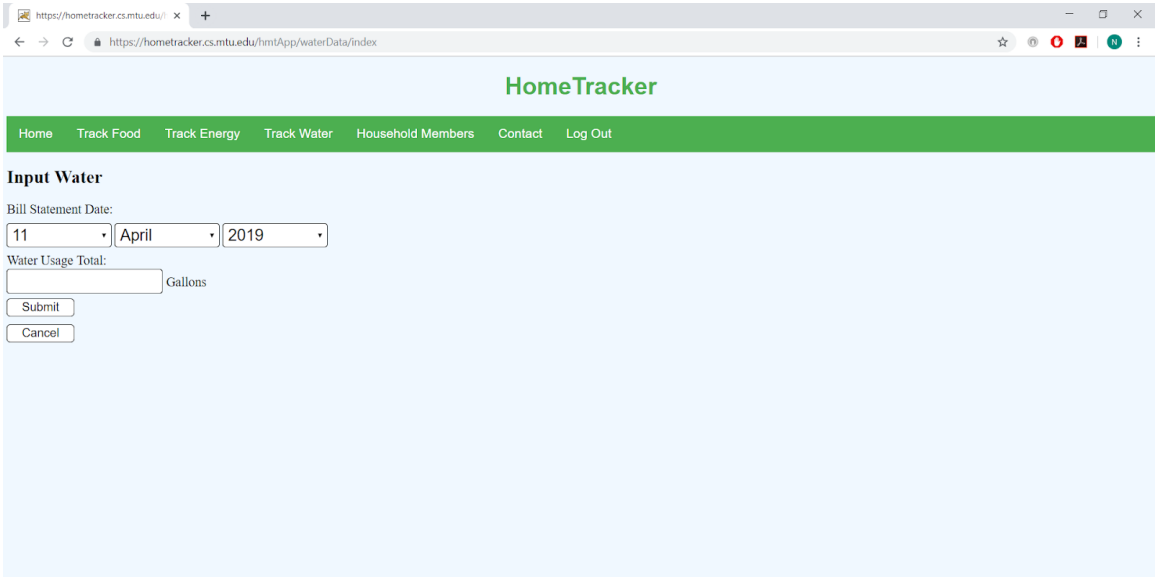

Figure 3.7.1 Screen capture of Water entry from in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

3.8 Scientist Views

After completion of the food pilot study, the FEWCON researchers noted they wanted to be able to view collected FEW data as the study was ongoing. This was especially important for monitoring food data since food data is being collected for a total of four weeks out of the 12 month study. If a problem was occurring with how data was uploaded by participants, it could be addressed in a timely manner.

In addition to the categorization employees having admin access to the HomeTracker, the FEWCON researchers also have admin access to view the collected FEW data. The FEW data is broken down by participant. The scientists start off by viewing a table that lists all participants. From there, the researchers can select to view the participants' household information, both categorized and uncategorized FAH purchases, FAFH purchases, energy data, natural gas data and water data. All the information is displayed in a table with the corresponding timestamp of when the data was uploaded.

3.9 HomeTracker Contact

To further the usability of HomeTracker, an email is included as a footer on each page of the web app. The footer prompts the participants to send an email if they have any questions, concerns or run into any problems while using HomeTracker. To streamline means of sending an email for support, a contact page is included in HomeTracker. This contact page allows participants to send an email directly from HomeTracker.

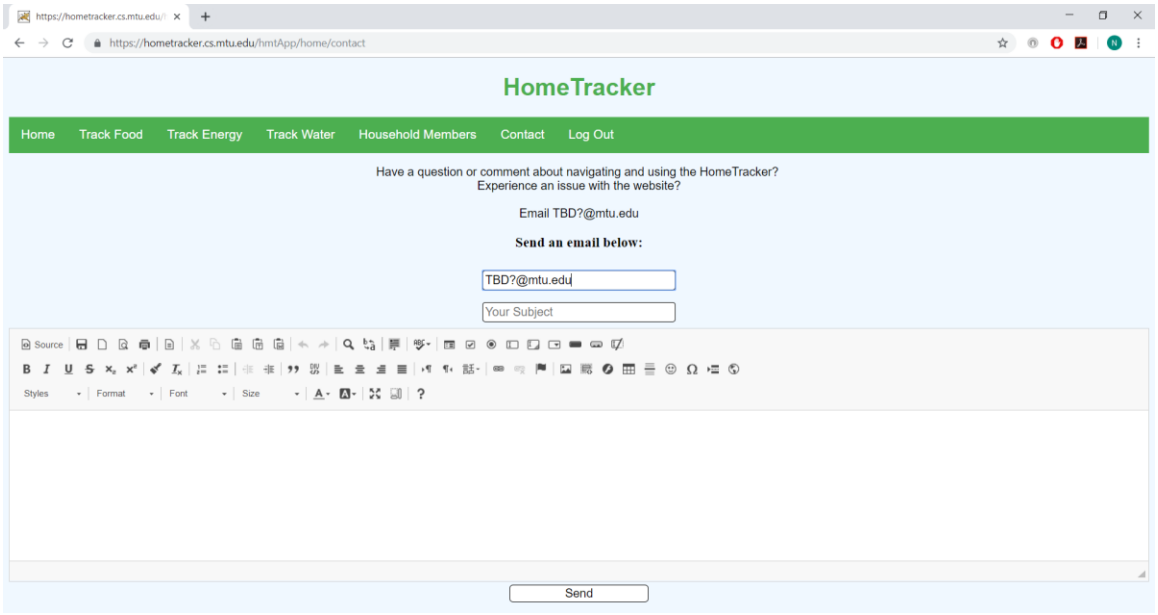

Figure 3.9.1. Screen capture of the Contact form in HomeTracker. Image source: https://hometracker.cs.mtu.edu/hmtApp/.

4 HomeTracker Next Steps

The technology behind HomeTracker itself is not groundbreaking but the problem that HomeTracker is addressing is an area of research that few studies have focused on. Throughout research and development of HomeTracker, a few potential technologies were found to be promising yet were either at a stage where they were not quite ready to be integrated into third party services, such as HomeTracker, or were too costly to be integrated into the FEWCON study. With this, focusing on creating HomeTracker as an MVP proved to be an achievable goal. There is room for HomeTracker to grow, and as technologies are released and shown to be stable, they can be added into the HomeTracker to further streamline data entry, minimizing the burden of data entry for the user and decreasing the introduction of error.

There are improvements that can be made to HomeTracker in the immediate future. The current front-end design of HomeTracker is simple and minimalist, but could be made more visually appealing. In combination with having little web development experience prior to the FEWCON project and the constantly changing requirements of the HomeTracker, minimal time was spent designing the front-end. Having a more appealing design may make the experience more enjoyable for HomeTracker participants.

The process of creating a user account could be changed within HomeTracker. Currently, the Spring Security UI plug-in is being used, but it was found to be challenging to override the default process of creating an account and logging in to HomeTracker. The default Spring Security does not have an error for having unique emails across user accounts. Currently, if a user tries to create a new account using an email that already has an account associated with it, a message is displayed saying “there was an error processing your registration”. It would be more beneficial if this error message was explicit in stating that the email is already in use with another account. Updating the login procedure so that users cannot log in to multiple sessions (be logged in to HomeTracker on multiple devices at once) is ideal to eliminate possible data inconsistencies between sessions. Adding in functionality that allows for the FEWCON researchers to see how much time participants are spending on HomeTracker is beneficial to the planned study.

The HomeTracker was developed to be used on larger screens, such as desktops or laptops, but not developed with the mobile user in mind. Making HomeTracker mobile-friendly would increase the ease-of-access to the web app for users. From the results gathered from the food pilot study, it’s anticipated the majority of users will access HomeTracker via a computer and not a phone. It is envisioned that participants will likely perform the process of uploading receipt images to HomeTracker from a phone. Ensuring the process of logging in and uploading receipt images is mobile friendly is ideal.

Before the FEWCON study begins, displaying intervention messages and surveys to the participants needs to be integrated into HomeTracker. How participants should view inputted FEW data also needs to be decided. Currently users are able to view the FEW

data that has been submitted in respective tables. Viewing this data may be more engaging if it is displayed as a chart or graph.

There were issues identified in the process of uploading receipts from the food pilot study. About 10% of the receipts uploaded during the pilot study were unreadable, either because the photo was too small and blurry or because the participant uploaded a PDF. Setting a minimum required file size to the HomeTracker would mitigate the issue of receipt images being too small when uploaded. The images are being stored as a longblob in the database. This may be affecting the ability to display PDFs on the HomeTracker screen. Finding a solution to allowing PDFs to be uploaded is needed within HomeTracker.

A final improvement that could be made to the HomeTracker is in data management. There are views in place on the HomeTracker for the FEWCON researchers to quickly view the data that participants have uploaded. These views will need to be expanded upon once the surveys and intervention messages are integrated into HomeTracker. In order to do any processing on the data, a CSV file or equivalent is ideal. In order for the researchers to obtain a CSV of the data, I currently download the data myself and share the file with the team. Adding download data functionality into HomeTracker would further the usability for the admins of the app.

5 Takeaways

Implementing HomeTracker was a huge learning experience for me. It provided me insight in working with a research team that was multidisciplinary and geographically located, which is not an experience I received from my other coursework. When given an assignment for a class, there is a set rubric associated with it. With HomeTracker, this was not the case. When I joined the FEWCON project to develop HomeTracker, many of the design decisions of HomeTracker were unknown. The FEWCON team had to come up with solutions to the questions at hand that they believed would provide the most success during the planned study. Having a diverse team, there were many viewpoints to consider when making a decision. Needing to be adaptable to the changing requirements and patient with the process allowed me to grow as an individual and also as a team member.

In addition to the soft skills I expanded, I was able to further my technical skills. I gained web development experience from front end to backend. Considering security requirements, maintaining a database and deploying web apps to a server was something I hadn't previously done. The perspective I obtained from working on HomeTracker and with the greater FEWCON team is one that I will carry with me as I begin my career in industry as a software engineer.

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A Accessing the HomeTracker

The HomeTracker web application can be accessed via the following link: https://hometracker.cs.mtu.edu/hmtApp.

B Copyright documentation

All images in this document are screenshots of the web application, HomeTracker, I developed. HomeTracker is hosted on a Tomcat server maintained by Michigan Technological University IT.