TAQI:

A Google Timeline and Air Quality Analysis App

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Abstract

Air pollution levels today are incredibly high, updated statistics from the World Health Organization (WHO) state that nine out of ten people breathe air containing high levels of pollutants. Unfortunately, it is difficult and costly to estimate the air quality someone has been exposed to on an ongoing basis. This Master's report presents TAQI: A Google Timeline and Air Quality Analysis app, the first system to present a user with detailed information about their personal air quality exposures. In integration tests, TAQI achieved a reduction in data sent to third-parties by over 99%. In tests with college students who had nearly no prior knowledge on air quality statistics, participants were able to determine a few basic statistics in less than 4 minutes. Both of these metrics compare favorably to that of current systems, which require users to upload all of their data to a third-party system – and, when users were asked to find even the most basic statistics like min and max values with the existing system, only 1 of 10 testers were able to produce any accurate data within five minutes. Overall, these results point towards a new era of information access to guide healthy living. With TAQI, people can track and see where their highest levels of air pollutants are coming from allowing them the chance to improve their health and maybe even save their lives.

1. Introduction

Air pollution levels today are incredibly high. Statistics from the World Health Organization (WHO) state that nine out of ten people breathe air containing high levels of pollutants. These pollutants take the lives of 7 million people every year (World Health Organization 2018). This is compared to the 3.2 million deaths reported in 2012 of similar causes (Brauer, et al. 2012).

Key particle pollutants, known as particle matter (PM), are made up of many elements, including acids like nitrates and sulfates, organic chemicals, metals, soil or dust particles, and allergens like fragments of pollen or mold spores. Particles smaller than 10 micrometers in diameter are of the greatest concern (United States Environmental Protection Agency 2003). These particles can penetrate deep in the lungs and could potentially end up in the bloodstream, damaging the lungs and heart (United States Environmental Protection Agency 2003). Fine particles often found in haze and smoke are 2.5 micrometers or less, known as $PM_{2.5}$, whereas coarse particles such as those found in dust have a diameter between 2.5 and 10 micrometers, known as PM_{10} (United States Environmental Protection Agency 2003).

The impact of potential health problems is directly related to exposure to these particles. Short-term exposures over the course of a few hours or days can aggravate lung disease causing asthma attacks and acute bronchitis (United States Environmental Protection Agency 2003). It may also increase risk of respiratory infections (United States Environmental Protection Agency 2003). Those who have a history of heart disease are also at increased risk of heart attacks and arrhythmias (United States Environmental Protection Agency 2003). Long-term exposures experienced by people who live in areas containing high airborne pollutants, like those mentioned above, have been seen to have reduced lung functions as well as develop chronic bronchitis (United States Environmental Protection Agency 2003). The worst-case scenario is death (United States Environmental Protection Agency 2003).

Unfortunately, it is difficult and costly to estimate the air quality someone has been exposed to throughout their life. Systems exist to help users to track their location and see where they've been. Google Maps and Google Timeline are a leading example of this (Google LLC n.d.). Systems also exist that allow users to see various types of historical data such as global $PM_{2.5}$ values, the leading examples for these types of systems are maps and servers using ArcGIS technology (ESRI n.d.).

For those with money to invest they can purchase a device such as that shown in Figure 1. This device is a Dylos DC1700. Many studies have used this device to determine a person's

Figure 1: Dylos DC1700 and GPS strapped to a backpack

specific, short-term, $PM_{2.5}$ exposure. A study performed in Scotland in 2014 used this device coupled with a GPS to perform their experiment. The study states that the device on a full charge can only stay on for about six hours (Steinle, et al. 2015). And based on current eBay prices they are selling for almost $500 used (Ebay n.d.). By using a device like this the user is also required to extract the data from the system manually and compute their own exposures.

There exists a need for a way to estimate one's individual air quality exposure while also reducing cost and effort. To meet this need, this Master's report presents TAQI: A Google Timeline and Air Quality Analysis app (pronounced like "tacky"). This system is the first to present a user with detailed information about their individual air quality exposures. The system is an iOS app that consists of an air quality map as well as a heatmap of the user's past locations. It allows the user to analyze their specific exposure which will compare their locations to air quality readings provided by Columbia University's SEDAC $PM_{2.5}$ global average ArcGIS Image Service (Columbia University n.d.). It is designed to be more secure than existing systems by only sending a limited set of sensitive, anonymized, data to a third-party server. It is also designed to be more efficient by calculating the user's statistics for them instead of relying on them to perform that task by hand.

TAQI was evaluated in two ways. The first, which consisted of integration testing with a sample dataset, measured the amount of data sent to third-party servers to ensure security, compared to a competing system. The second evaluation compared the usability of TAQI against a combination of a heatmap of the user's location history and a map of global $PM_{2.5}$ averages. Together, these studies confirmed the system's security, effectiveness, and usability.

The remainder of this document is organized in the following way. Section 2 outlines Related Work and limitations of existing systems. After, Section 3 presents TAQI and its implementation, Section 4 discusses the evaluation relative to existing systems. Section 5 summarizes conclusions and opportunities for future work.

2. Related Work

The global climate has been of interest to scientists for years and they have developed some technologies to aid them in their research. While these technologies have solved their immediate problems for use in research contexts, no similar system with high usability yet exists for the average person to assess his or her own exposure to particulate matter.

2.1. Specialized Hardware

As mentioned in Section 1, the Dylos DC1700 is a small, portable device that allows the user to track their air quality measurements (Steinle, et al. 2015). This system is especially good at capturing a person's short-term air quality exposure as the battery lasts six hours on a full charge and the system will re-write old data after about a week of continuous use (Steinle, et al. 2015). The system is also expensive to the point that many will find it unreasonable and unnecessary to purchase one for calculating their exposure unless absolutely necessary. This system also does not track a user's location, so another device would need to be used to perform that function (Steinle, et al. 2015).

2.2. Online tools for determining exposure and location

There are a couple tools online that could help users to find out their personal exposure. First, the user would need a log of where they've been. While one could perhaps guess where they've been, Google provides a better solution. Since 2015 Google has had a feature embedded in Google Maps called Google Maps Timeline that allows users to see where they've been

(Google LLC n.d.). While Google Maps Timeline displays points where users have been, it doesn't provide useful information about how often you stay at one place.

A common solution to visualizing amounts or lengths of time, is a heatmap. There is an open source website name Location History Visualizer that allows you to take your Google Maps Timeline data and will produce a heatmap (Patt n.d.).

The third step in the process of assessing one's own particulate exposure would then be to couple the Google data, above, with air quality data. ArcGIS is a mapping software that allows companies to overlay data onto maps. Columbia University has developed such a map, SEDAC, that displays global $PM_{2.5}$ values (Columbia University n.d.). Users could then use these three systems in combination to estimate their exposure.

Unfortunately, ArcGIS/SEDAC doesn't allow users to calculate specific readings. It only gives a range for each color on the map. See Figure 2 for a screenshot of SEDAC's $PM_{2.5}$ map. To date no system has been introduced that allows users to conveniently and efficiently estimate their specific air quality exposure. TAQI is the first such system.

3. Solution

TAQI is the first system to present a user with detailed information about their specific air quality exposures. It is designed to be more secure than existing systems by only sending a limited set of sensitive, anonymized, data to a third-party server. It is also designed to be more efficient by calculating the user's statistics for them instead of relying on them to perform that task by manually integrating disparate tools as discussed in Section 2. The system is an iOS app that consists of an air quality map as well as a heatmap of the user's past locations. It allows the user to analyze their specific exposure which will compare their locations to air quality readings

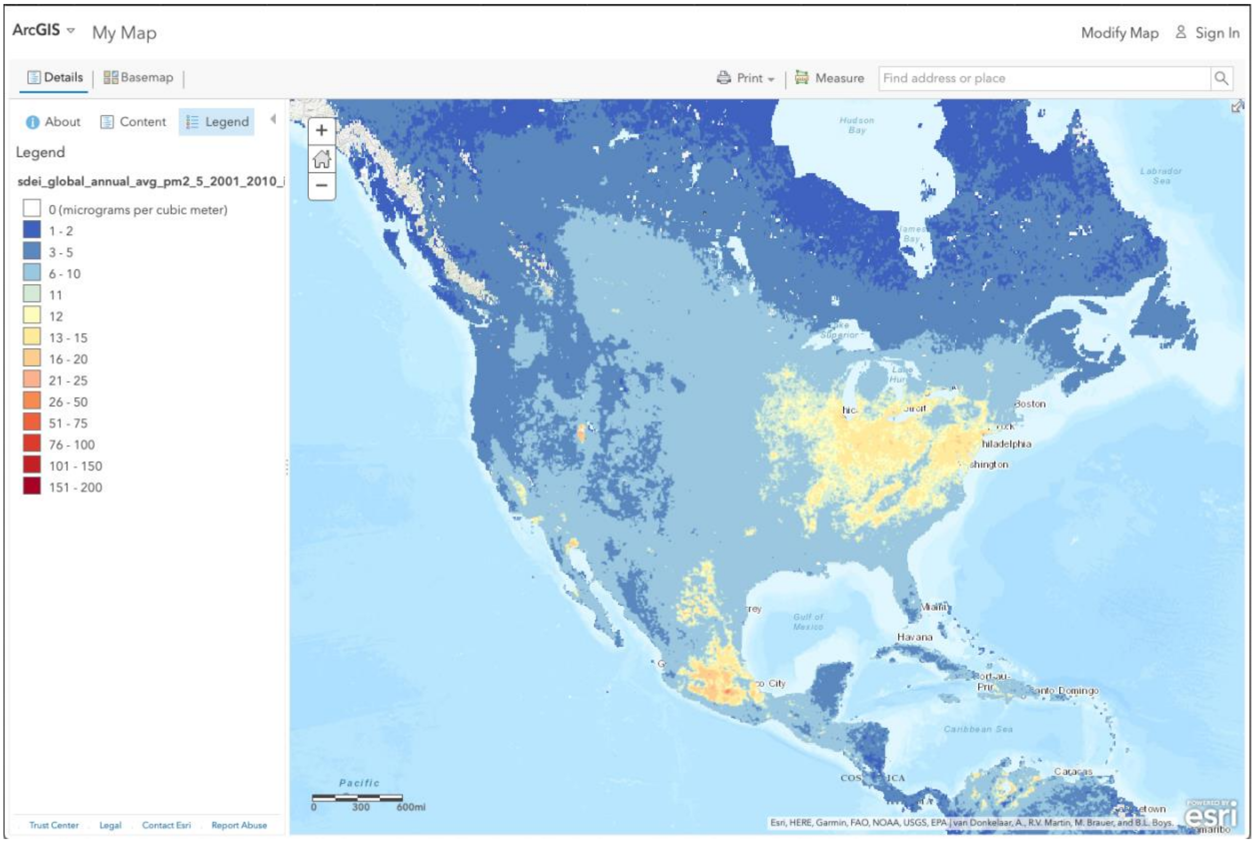

Figure 2: SEDAC PM2.5 Map

provided by Columbia University's SEDAC $PM_{2.5}$ global average ArcGIS Image Service (Columbia University n.d.). Figures 3-8 show the different pages of the app which the subsections below describe in detail. Subsection 3.4 goes over implementation details.

The following is a list of steps the users take through the app.

1. The user is required to download their Google Timeline data by either tapping on the '+' symbol at the top of the document browser page or using another way to get the data onto their device.

    1.1. Follow the steps to download and extract the file onto the device.

2. Tap on their Location History file which will bring up the main interface of the app allowing them to view an air quality map and a heatmap of their locations.

3. Tap the ‘Analyze’ button to bring up the user’s air quality statistics.
4. Tap the ‘info’ button to view a description of the services used in the app.

3.1. Document Browser (Figures 3 & 4)

The Document Browser is the first screen users see when they open the app. This is where they can select their location history file downloaded from Google Timeline. This is implemented with Apple’s built in file manager with the UIDocumentBrowserViewController (Apple, Inc. n.d.). The download instructions page can be accessed by selecting the ‘+’ symbol at the top of the document browser. This is a list of steps that walk through the user in downloading their data from Google Timeline and importing it into the app. While this process isn’t the most straightforward it is assisted by the instructions in the app, without these the user would have to figure out how to download their own data from Google. The link at the bottom of the

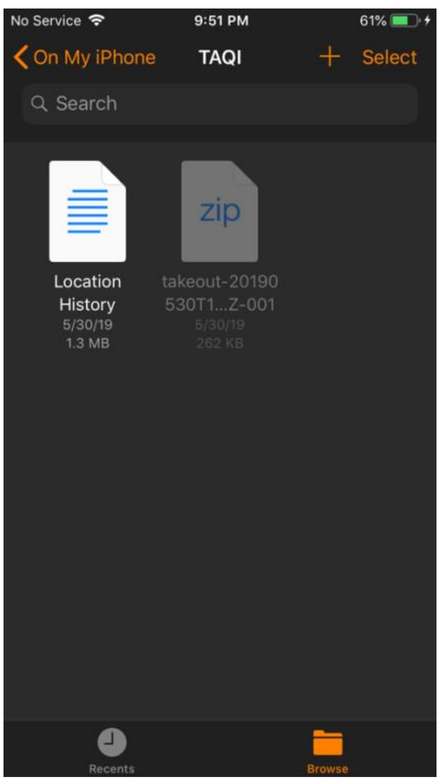

Figure 3: Document Browser

Figure 4: Download Instructions

instructions selects only the location history as the data to download which reduces the need for users to click through and deselect all other data types that Google allows them to download.

3.2. Air Quality and Location History Maps (Figures 5 & 6)

These maps are the main visuals for the app. They allow the user to quickly switch back and forth between an air quality map and their location history so they can see where they've been often and compare it to the air quality map. These maps are implemented in different technologies because of each of their limitations. ArcGIS maps are easy to show raster images (like the one of NO_2 displayed in Figure 5) and Google's maps are really easy to show heatmaps in (like the one in Figure 6). These maps are synced so that when quickly switching back and forth you end up looking at the same spot on the map that you panned to in the other map. Meaning that if a person is focused on Corvallis, OR in the Air Quality map, then pans to

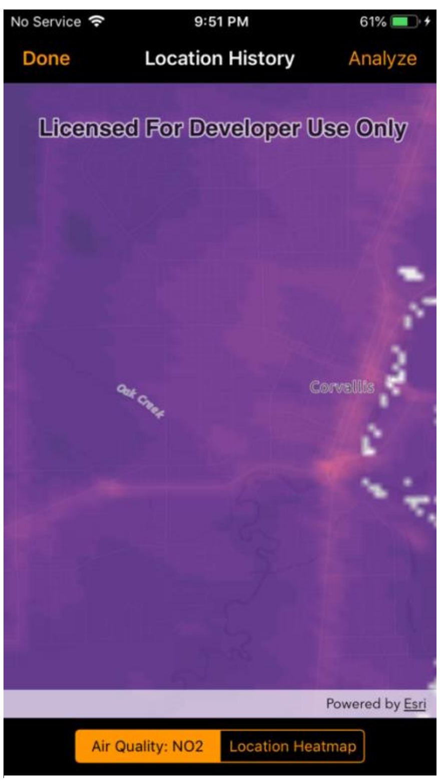

Figure 5: Air Quality Map

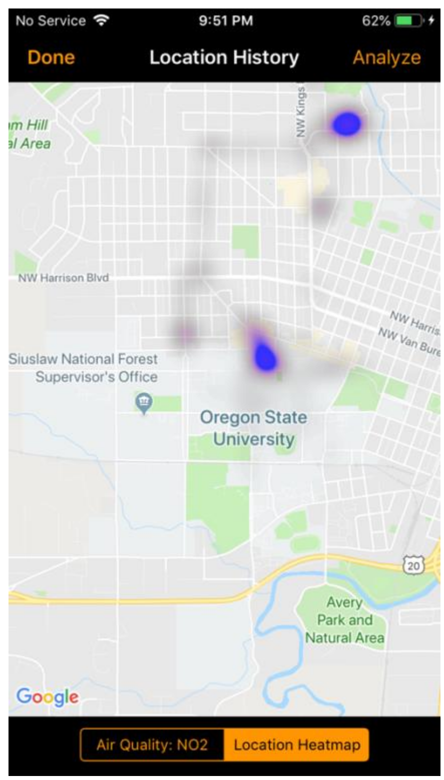

Figure 6: Location Heatmap

Portland, OR, and orients the map to such that East is pointing towards the top of the device, the Location Heatmap will be in the same position, orientation, and zoom level as the Air Quality map. This allows for quick comparisons rather than having to switch and line up the maps manually as in existing systems.

3.3. Air Quality Measurements, Mean, Standard Deviation, and Info Screens (Figures 7 & 8)

The air quality measurements screen is where this app stands out. It can be navigated to by pressing the “Analyze” button on the top-right of the map screen. While its simple design conveys information quickly to the user, a lot is going on behind the scenes. When first loading the air quality and location heatmaps (in Step 3.1 above), the app parsed the file and generated a

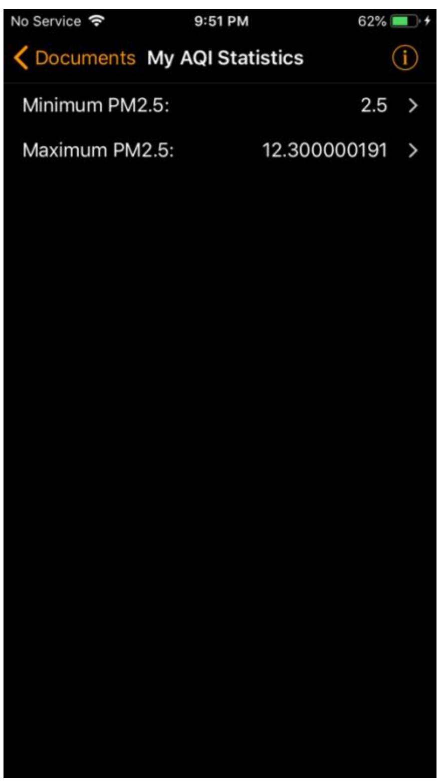

Figure 7: User's Individual Air Quality Measurements

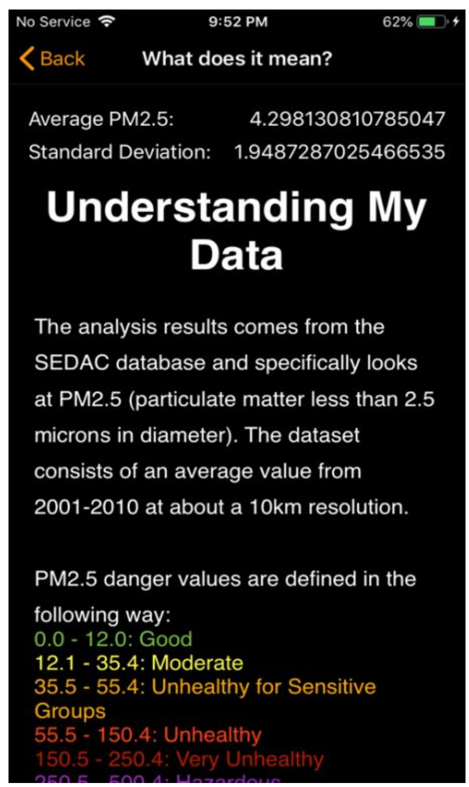

Figure 8: Mean, Standard Deviation, and Info

Location instance for each coordinate in the Google Maps Timeline file. Location is a custom Swift class that has a required timestamp and coordinate value, with optional accuracy, heading, altitude, vertical accuracy, and velocity fields that may or may not be present in the Google Maps Timeline file.

Once a Location instance is generated for each coordinate, they're grouped into Path instances. Thus, the path-based representation used within TAQI summarizes the original dataset containing all the user's previous locations. This is done to reduce the amount of data sent to third-party servers, both increasing efficiency of the system as well as security by stripping out paths that are close together. Users choosing to manually integrate existing tools (as in Section 2) rather than using TAQI would instead need to upload all of their previous locations to the server—increasing the amount of bandwidth and latency required, as well as potentially compromising their privacy. TAQI's path-based approach, in contrast, helps to improve efficiency and protect privacy.

Specifically, a Path is defined as a set of Locations where the difference between coordinates is at most fifteen minutes but must include at least two Locations. It is important to note that the Paths are not temporally weighted. Meaning there is no difference if it takes someone 10 minutes to walk around the block or 2 hours, the results generated will be the same. Once the Paths are generated, a subset of these Paths is created with the constraint that a new path cannot be added to the subset if its first coordinate is within ten kilometers of the first coordinate of the last path added to the subset. For example, let's say someone commutes from their house to Oregon State University and back which has a direct distance of 2km. Let us also assume that the path generated from their travels to Oregon State University are included in the subset. Because the starting point on their commute home (Oregon State University) is less than

10km from their house (the starting point of the last path added), the path generated by their commute home will not be added to the subset and therefore not be sent to the third-party servers.

Ten kilometers was chosen because that is about the resolution of the SEDAC $PM_{2.5}$ database the app is querying (Columbia University n.d.). The querying of the data is also multithreaded to reduce wait times on the user.

The average and standard deviation of the user's $PM_{2.5}$ exposure is found under the info button on the analysis page. A description of the SEDAC server as well as a table of values the U.S. Environmental Protection Agency produces of good to hazardous $PM_{2.5}$ ratings is found on the info page as well.

3.4. Implementation Details

TAQI is implemented in Apple's open source programming language Swift (Apple, Inc. 2019). It is designed for iPhone and iPad devices and runs on all devices running iOS 12.1 or later. (Figure 9 shows an architectural diagram of the system)

The document browser page is implemented using UIDocumentBrowserViewController which is an off-the-shelf implementation provided by the iOS SDK that allows users to interact with files directly on their device (Apple, Inc. n.d.).

The instruction page where users are told how to download their data is implemented by a standard UIViewController with a UITextView inside of it detailing the instructions. A button at the bottom opens Safari (iOS's web browser) to Google Takeout with Location History selected where users can download their location history file. The text was written in an RTF file and imported into the app's bundle where the text is read and displayed in the UITextView. The app bundle is the set of files used in the app, this includes source code, images, supporting files, supporting frameworks, and configuration files.

The air quality and location heatmap page is implemented with three different supporting frameworks. The first is ArcGIS's iOS SDK version 100.5.0 released April 9, 2019 (ArcGIS 2019). This framework was used to display the raster image of NO_2 and can be utilized in the future to display any raster locally on the device (as this one is) or one from an ArcGIS Image Service (like SEDAC). The raster is included in the app's bundle similar to the instructions mentioned above. This file is the largest part of the app, it is 143MB while the entire app is 313.4MB. The second and third frameworks are the Google Maps SDK for iOS (Google LLC 2018) and the Utility Library for Google Maps SDK for iOS (Google LLC 2019). The first Google framework was used to show the map part of the location heatmaps while the utility library was used to generate the heatmaps on-device.

The analysis page displays min and max values of $PM_{2.5}$ using a UITableViewController. The values are calculated as mentioned above by selecting paths that have a starting point less

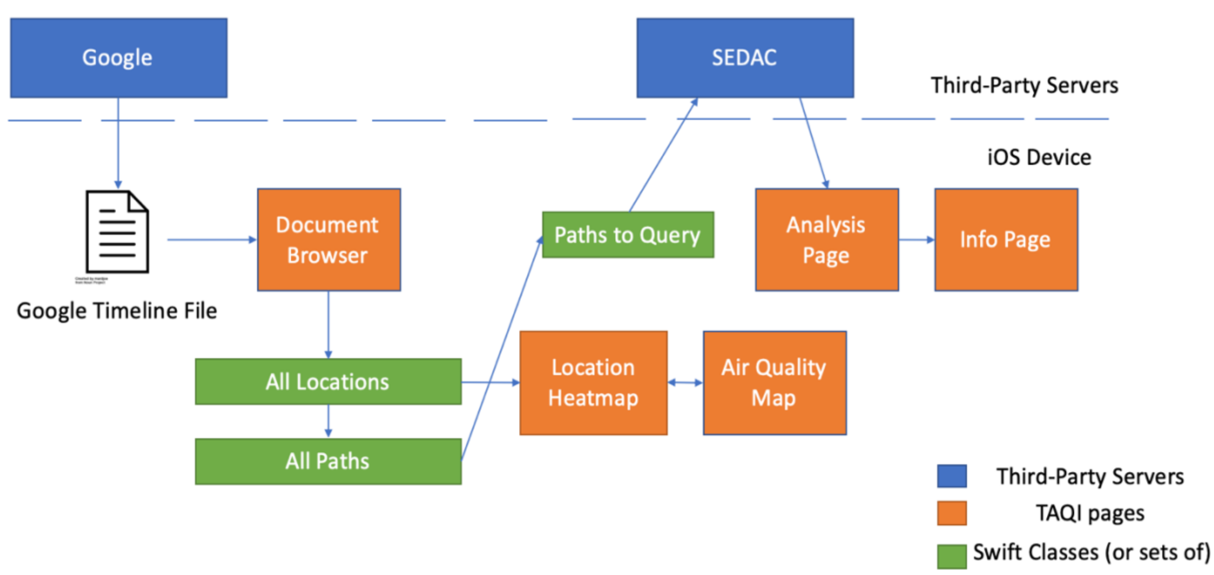

Figure 7: TAQI takes a file downloaded from Google Timeline, saves it to the Document Browser, parses the file for Locations and Paths, queries SEDAC with select paths, and reports back to the Analysis Page.

than 10km from the last path added. This was done to reduce the time it takes to get results back as well as limiting the data sent to a third-party server making such a process more secure.

The info page is implemented the same as the instructions page. The info text is an RTF file included in the app's bundle.

4. Evaluation

TAQI's evaluation consisted of integration testing to evaluate security and effectiveness, followed by a lab study to evaluate usability. Integration testing assessed how well the system performed compared to existing systems. The user evaluation focused on usability of the system compared to existing, affordable, systems.

4.1. Integration Testing

The integration tests were aimed at answering two questions. (1) First, how much does the app reduce the size of the dataset sent to the server, compared to sending all data transmitted? (2) Second, with the reduction of data, how close will the value of min/max/mean be within of the value produced considering all data points?

Methodology

Sample: With accurate personal location being very private, only two data sets were obtained. One was a medium-small data set spanning 6 months while the other was fairly large spanning about 3 years. The data sets obtained were those of the author and Dr. Hystad respectively. Dr. Hystad is an assistant professor at Oregon State University in the College of Public Health and Human Sciences.

Tests: Each data set was separately loaded into TAQI, and the "Analysis" button was pressed to calculate the minimum, maximum, mean, and standard deviation of the data set. To determine the "true" values of the dataset, meaning using all points, a Python 3 script was developed to query the same SEDAC server with all data points.

Data Acquisition: Several measurement techniques were used to gather data to answer the above questions.

To get the starting size of each of the files in KB, the file inspector in the Finder application in MacOS was used. To get the amount of data sent to the third-party server (SEDAC), the developer application (called Instruments) was used. This application comes bundled with the iOS development IDE (Xcode). Network traffic was monitored in Instruments, looking for any outgoing data to servers containing either "sedac" or "columbia.edu."

The min/max/mean/standard deviation of $PM_{2.5}$ from the data sets were either printed via console message from the Python script taking into account all values or recorded from the TAQI interface taking into account a selected number of values determined by the algorithm described in section 3.3.

Analysis: (1) The percentage of data sent was calculated by taking the KB transferred to the third-party server and dividing it by the original file size of the data set.

(2) For each of the min/max/mean values, the smallest of the two between the set from the Python script and the set received from TAQI was divided by the larger of the two creating a percentage.

Results

(1) Percentage of data sent: In both of the data sets, TAQI managed to send less than 1% of the original data. 0.9% and 0.6% of the original data was sent to third-party servers with the medium-small and large data sets respectively.

(2) Difference in data: The mean on the large data set was the only one off by more than 10%; it was off by 20%. See Tables 1 & 2 for data received. As mentioned earlier the data generated by TAQI, as well as the data from the Python script are not temporally weighted. This could potentially produce different results.

Table 1: PM2.5 values from All Data

	Medium-Small	Large
Minimum	2.3	1.1
Max	12.9	85.3
Mean	4.162	4.477

Table 2: PM2.5 values from TAQI

	Medium-Small	Large
Minimum	2.5	1.1
Max	12.3	82.3
Mean	4.298	5.594

4.2. User Evaluation

The user evaluation investigated how well college-aged students could extract basic statistical data from TAQI compared to the current method of using the Google Timeline Visualizer and the SEDAC ArcGIS Map websites.

In particular, the study focused on three questions: (1) Could college-aged students extract as much basic statistical information from TAQI as they could the combination of the existing methods? (2) Could they do so at least as quickly as with existing methods? (3) Would they judge the app as usable as the existing methods?

Participants: College-aged students (N=10) were recruited by approaching people in a graduate office. This was considered an appropriate target population because college-aged students are typically the most familiar with both how apps and websites tend to work.

Procedure: The two websites, SEDAC ArcGIS Map (Columbia University n.d.) and Location History Visualizer (Patt n.d.) were presented to the user as well as TAQI. Both TAQI and the location visualizer were loaded with the medium-small data set discussed earlier. This data set was reasonable because it was considered not overwhelming for the user while also providing a realistic data set. Each participant would use both systems, but would randomly start on one, following a counterbalanced design. That is, each participant was randomly assigned a starting technology, either TAQI or the existing systems.

Each participant was given a quick overview of what each of the websites did as well as a description of the purpose of TAQI. It is important to note that the users were not given a tutorial on either technology. A tutorial on TAQI would give away what the user was asked to do and only giving a tutorial on the websites would give them an unfair advantage.

The participants were asked to find which locations the user had been that had the highest and lowest values of $PM_{2.5}$ as well as what those values were. They were asked to find the average $PM_{2.5}$ of the user as well as the standard deviation. Finally, the user was asked what group (Good/Moderate/Unhealthy for Sensitive Groups/Unhealthy/Very Unhealthy/Hazardous) each of the min/max/mean values fell into. They were asked to do this for each system and fill out an exit survey. The users were given five minutes to complete all of the tasks for each system then switch to the next system. Five minutes was determined as a fair amount of time because the participants were students selected from a CS grad program. A recent study noted that developers typically spend between 0.3 (±2.6) and 2.0 (±6.5) minutes on a task before switching to a new one (Meyer, et al. 2017).

Data Acquisition: The total time it took for users to finish the set of tasks for each system was determined by a stopwatch. Their actions and voices were also recorded using screen capture software. Usability ratings were obtained by an exit survey which asked users to rate both systems as well as give feedback on both systems (Table 3, below).

Analysis: Time-to-finish was recorded as well if users gave up and refused to keep trying or if they mentioned a reason they didn't finish. The average response was calculated for each item in the exit survey. Statistical tests were not performed in part due to the small number of participants. Ideally, the difference between TAQI and the competing systems would be large and obvious enough to promote adoption.

Table 3: Exit Survey questions

Exit Survey
All questions are on a 5-point Likert scale (strongly disagree through strongly agree) and was asked each question for both TAQI and the existing systems. (noted here as <technology>).
The <technology> was easy to use.
I found what I was looking for quickly using the <technology>
I would use the <technology> in the future
I would pay to use the <technology>
I felt the <technology> was secure
General feedback on the <technology>

Results

Task completion: Of the 10 participants, one of them successfully extracted any information from the websites – i.e., the first step required for the task – but even this participant did not complete the entire task. In contrast, all TAQI users obtained data, and 7/10 competed the required tasks with TAQI within 5 minutes. On average, these users completed the tasks with TAQI in 3.6 minutes. Overall, these 7 users were more successful with TAQI than with the competing systems, and on average they completed the entire task more quickly than the one partially successful user could even do the first part of the task with the existing websites. Table 4 outlines the average completion time as well as the fastest and slowest times for each system.

Table 4: The efficiency of users with TAQI met or exceeded those who used the websites

	TAQI (min: sec)	Websites (min: sec)
Average Completion Time	3:38	5:00
Fastest	1:58	5:00
Slowest	5:00	5:00

Perceived Usability: On average, users either agreed or strongly agreed that the app was easy to use, they found what they were looking for quickly, they would use it in the future, and that they felt it was secure. In contrast, the existing websites scored on average between disagree to neutral for all questions except the one that asked if users felt it was secure (which scored between neutral and agree). See Figure 10 for usability ratings.

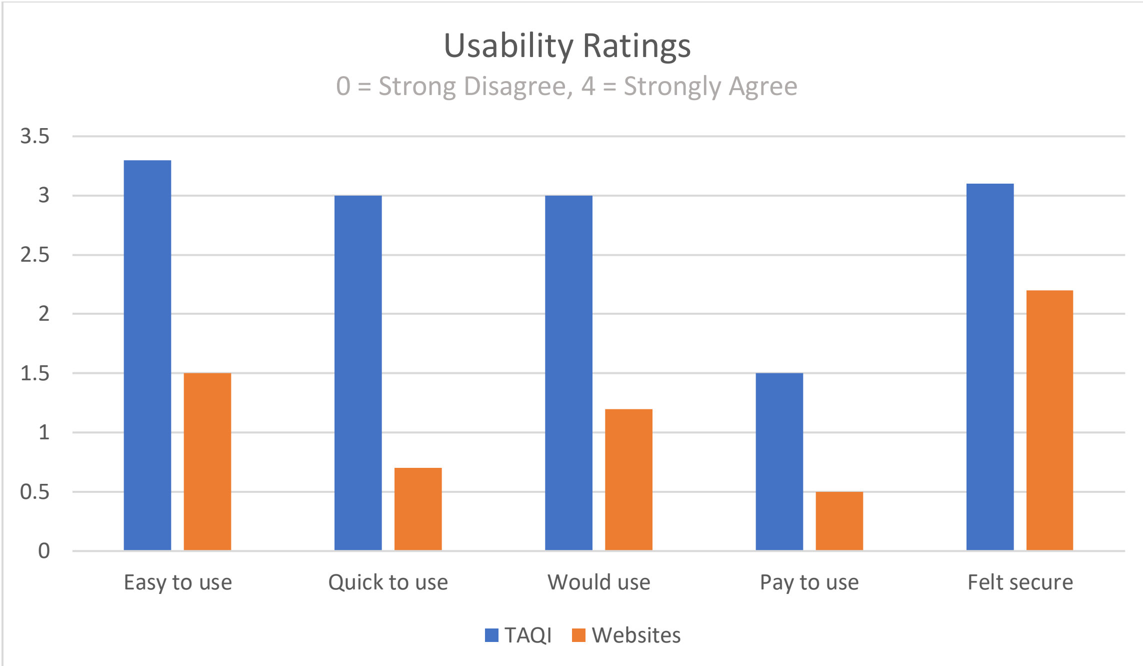

Figure 8: TAQI scored better in all areas

5. Conclusion

TAQI is the first to present a user with detailed information about their specific air quality exposures. The system performed successfully in all evaluations. In integration tests, TAQI saw a reduction in data sent to third-parties by over 99%. In the user study, college students with nearly no prior knowledge on air quality statistics were able to determine a few basic statistics, on average, in less than 4 minutes. Both of these metrics compare favorably to that of the current systems, which require users to upload all of their data to a third-party – and that, when users were asked to find even the most basic statistics like min and max values, only 1 out of 10 were able to produce a single result within five minutes.

Overall, these results point towards a new era of information access to guide healthy living. With TAQI, people can track and see where their highest levels of air pollutants are coming from, allowing them the chance to improve their health and maybe even save their lives.

These promising results for TAQI could serve as a good starting point for future enhancements.

First, the inclusion of temporally weighted data should be added. This would mean giving more weight to paths where users spent longer amounts of time. This small change could perhaps produce more accurate results. Further work is required to determine if this inclusion would produce better data for the cost of this step in the algorithm.

Second, even though $PM_{2.5}$ is one of the most dangerous types of pollutants, there are many more that researchers are tracking and might be put in a form that could be integrated with the TAQI system. Thus, TAQI could play a role as a framework for tapping into these resources. For example, currently in the user interface, there exists a map of NO_2 particles in the air for the Pacific Northwest. In the future, when worldwide data on NO_2 exposure becomes available to the public, the app could be used to leverage that data.

Lastly, even beyond past air quality, other environmental factors could be considered, such as noise pollution or crime levels. Maybe someday there will be an app that will allow a user to upload historical location data, then explore different exposures to a variety of various environmental health risks, allowing them to make informed decisions on where to travel to or even where to live.

In conclusion, TAQI is an important innovation focused on usability that opens new directions for a world focused on individual health. It performed well in terms of effectiveness, security, and usability. Outfitting it with new features and capabilities could propel it and its users into a happier and healthier world.

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