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Landfill Hunter: Learning about Waste through Public Participation

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ABSTRACT

Landfills are the most ubiquitous and expedient means of waste disposal, prevailing over any economic, logistic or political obstacles. Landfills, however, are far removed from most of society and their administration, operation and maintenance are often opaque. This research uses public participation to generate, verify and enhance existing data about the size and location of current landfills in the US while simultaneously providing users an innovative way to see and explore landfills. An online crowdsourcing tool, Landfill Hunter, was built to facilitate participation and populated with data from the Environmental Protection Agency (EPA). Participants identified a total of 729 landfills. Using this data, we estimate the area of individual landfills and calculate the cumulative land area of landfills in the US, which is approximately twice the size of New York City. In this paper, we emphasize learning outcomes that participation in this crowdsourcing initiative can generate, both online and offline, as well as creative ways that participants can visualize the resulting data.

1. INTRODUCTION

In January 2016, one of India's largest landfills caught fire filling the city of Mumbai with thick smoke that lasted for several weeks and was visible from space (Tharoor, 2016). Thousands of people, many of the poorest in Mumbai, were exposed to the hazardous smoke daily. In 2015, a landfill in Shenzhen, China collapsed resulting in a landslide killing 69 people (Buckley and Ramzy, 2015). Similar landfill-related deaths have taken place in the Philippines in 2000, Athens (Greece) in 2003 and Bandung (Indonesia) in 2005 (Koelsch et al., 2005). Investigations into the causes of these events continually reveal evidence of mismanagement, inadequate oversight and insufficient regulations. In the United States (US), landfills continue to play an important role in waste disposal. In 2012, 251 million tons of municipal solid waste (MSW) was generated, of which 53% was disposed in landfills (The US Environmental Protection Agency, 2014). Though

the percentage of solid waste disposed in landfills has decreased in the United States since the 1980's due to increased recovery rates, overall MSW generation has increased and landfills continue to be the primary method of waste disposal due to their simplicity and cost-effectiveness (Eiselt, 2007; Barrett and Lawlor, 1995).

The potentially dangerous, yet unshakable role of landfills in society reveals an intricate and complex relationship that spans numerous areas including politics, economics and environmental justice. Society's mentality towards waste, and its consequences, is often best described as 'out of sight, out of mind'. For most individuals, waste is collected curbside and never seen again. While this context describes most of society, significant portions of the population experience the effects of landfills daily. Wade and Bullard (1991) describe the social justice impact of landfills in the US highlighting the disproportionate share of landfills being built and operated in low-income, working class, and communities of color. For these communities, waste is not whisked away to some remote location, but deposited in their own backyard instead. The effect of this 'out of sight, out of mind' mentality, combined with disjointed systems of waste collection and the undesirable nature of landfills, is a waste management system that is abstracted from society and, in particular, lacks transparency concerning its administration, operation and maintenance. Access to information, greater transparency and increased public awareness about the role of landfills in society are therefore the essential elements necessary to mitigate the potential negative impacts of landfills.

The goal of this project is to address the often hidden nature of landfills by bridging the knowledge gap between landfills and society. Landfill Hunter is an online crowdsourcing initiative that seeks to bring the role of landfills in society to the forefront and make the presence and operation of landfills visible to the public. The project uses citizen participation as a pathway for learning in order to promote a greater understanding of society's consumption and waste habits, and addresses openness and transparency about landfills by providing greater access to information. To this end, Landfill Hunter uses public participation to identify active and historical landfill locations in the US and estimate their total land area.

An important aspect of Landfill Hunter is to address the lack of publicly available data about landfills. Access to information and providing openness and transparency are important aspects for education and participation. Landfill Hunter promotes openness by allowing anyone to contribute data and using an open-source platform to enable reproducibility and further project development. The project also provides full access to user-generated data, which is immediately and freely available. This approach creates an environment suitable for the formation of communities, both online and offline that can further motivate and reinforce learning. The data generated from the project also has several potential uses that include providing new and comprehensive insight on the size and spatial distribution of landfills in the US, the ability to compare landfills and their surroundings, and most important, the ability to monitor and track landfills over time.

A unique aspect of this project lies in its ability to foster experiential learning by making visible society's waste generation habits. The role of public participation in waste management has historically been limited to decision-making processes in which local governments seek public input to determine the placement of waste management infrastructure (Carnes et al., 1998). Alternatively, recent community-based environmental monitoring efforts have proven to be an important aspect of public participation and can provide government agencies with tacit knowledge about local ecosystems (Conrad and Hilchey, 2011). In El Rama, Nicaragua, for example, members of the Public

Laboratory for Open Technology and Science used balloon photography to create geo-located maps of a nearby landfill (Danielsson, 2014). This data collection effort brought together local government members and the informal recycling community who used the maps to evaluate the landfill size and material content in order to generate economic opportunities for the informal recycling community and assess the landfill's impact on the surrounding wetland.

A similar participatory data collection effort was organized in the Czech Republic to map illegal dumping or overflowing waste sites (Kubásek and Hrebícek, 2013). Researchers developed a smartphone/mobile application to facilitate citizen participation by identifying and reporting illegal dumping areas. The crowdsourced effort identified 1,438 illegal dump sites and, as a result of the project, 200 sites were cleaned by the city showing not only the potential for the public to participate in identification of problem areas, but also the ability for citizen generated data to prompt the city's response to cleanup.

The Spanish-based non-profit organization, Basurama, is an artist collective that incorporates public participation in the creation of artwork and performances that explore culture and the environment (Mazon, 2014). Basurama, meaning love trash, uses the theme of waste to develop new perspectives and attitudes about the processes of consumption and waste generation. The organization collaborates with local community organizations to create participatory learning opportunities including the creation of interactive large-scale public art displays, developing and launching re-use initiatives and organizing workshops around visiting and documenting landfills.

1.1. Landfills in the United States

The history and evolution of landfills in society provides important insight about modern-day landfill operations and access to information. The practice of landfilling has existed for centuries, often in the form of open pit dumping. During the 20th century, however, the dramatic change in the type and amount of waste being generated, coupled with a lack of disposal regulations, led to increasingly hazardous and unrestrained landfill practices (Taylor and Allen, 2006). The first federal legislation regulating landfills was the Solid Waste Management Plan followed by the Resource Recovery and Conservation Act (RCRA), which defined the standards for sanitary landfilling and enabled the Environmental Protection Agency (EPA) to regulate and enforce landfilling practices (Opp, 2011). Following the enactment of RCRA, the EPA began to inspect landfills across the US, which led to the closure and abandonment of landfills failing to meet RCRA standards (Tarr, 1985). These inspections also led to the first comprehensive documentation of landfills in the US. In 1986, the EPA released the first list of all municipal solid waste landfills nationwide, which totaled 7,683 landfills. The list was updated in 1992 showing a decline in the number of landfills to 5,345, which declined even further to 3,581 in 1996, to approximately 2,300 in 1998 and 1,767 in 2002 (Eiselt, 2007; The US Environmental Protection Agency, 1996). As of 2012, there are 1,908 active landfills in the US (Van Haaren and Themelis, Nickolas, Goldstein, 2010). Though the total number of landfills has largely declined since the 1980s, the average size of a landfill is increasing (The US Environmental Protection Agency, 2014).

Information about waste is often sparse and difficult to access because of disaggregated disposal methods (Beigl et al., 2008). Similarly, information about landfills is limited because they are often privately owned and operated. Indeed, very little information existed about landfills prior to RCRA

because of diverse state legislation and lack of overarching federal legislation (Tarr, 1985). One existing source of data can be found in the EPA's Enforcement Compliance History Online[1] (ECHO) database, which was developed as a tool for the public to view compliance and enforcement activities of over 800,000 EPA monitored facilities under the Clean Air Act, Clean Water Act and the Resource Conservation and Recovery Act. The data is freely accessible and updated monthly (Bergeson, 2003). Despite being the most comprehensive and centralized dataset about landfills, the database faces several challenges. In particular, the evolution of landfill regulations led to categorization gaps and abandonment of numerous landfill sites that failed to meet RCRA standards (Tarr, 1985). This historical process presents fundamental challenges to collecting comprehensive data about landfills. EPA ECHO has also faced political controversy, online software glitches and the potential to be inaccessible as seen during the 2013 government shutdown (Opp, 2011; Fung, 2013; Johnson, 2013).

Other sources of information about landfills can be found through studies and reports published by various institutions and non-governmental organizations. The most thorough report was a joint study by BioCycle and the Earth Engineering Center of Columbia University published in 2010 (Van Haaren and Themelis, Nickolas, Goldstein, 2010). The report surveyed each individual state agency responsible for waste management to collect data about the total number of operational landfills in the US and their total remaining capacity. The data collected by the survey is based on the assumption that all states have reporting requirements and all waste management methods are reported to the appropriate state agency. The report found a total of 1,908 operational landfills, despite five states not completing the survey, and their remaining capacity ranged widely with varying units of measurement including cubic yards, years and tons.

2. PROJECT FRAMEWORK

Landfill Hunter is designed to expose participants to landfills in a novel manner. The use of Bing and Google Maps provide incredibly high-resolution maps for users to explore and virtually access landfills that are often off limits to the public (Figure 1). This detailed view of landfills shows participants specifically where waste is disposed, the manner in which it is disposed and the communities and environments that surround the landfill. Though landfills are often located in remote areas, a surprisingly large number of landfills are located near communities, both rural and urban. Participants witness and experience the diverse observable infrastructure including residential, commercial and industrial areas surrounding landfills. Qualitatively, this experience often reveals surprising patterns such as the frequent placement of golf courses nearby and the placement of landfills close to bodies of water. In this case, learning about landfills takes place through the process of participation.

Landfill Hunter uses humans to navigate geospatial information and visually identify the presence of landfills. Because landfills tend to have irregular shapes and sizes, computationally identifying landfills with image analysis software and modern machine learning techniques can be difficult. Humans, however, with the proper guidance and explanation, can learn to accurately recognize, identify and map geospatial features (Albrecht et al., 2014; Foody et al., 2013). Identification tasks can furthermore be distributed to multiple users in order to provide validation and accuracy metrics that can greatly enhance data quality. The Landfill Hunter application[2] was designed and built

[1] https://echo.epa.gov/

[2] http://crowdcrafting.org/project/landfill/

Figure 1. ***Long-haul truck dumping waste into a landfill. Screenshot taken from Google Maps.***

with the open-source online platform Crowdcrafting.org. Crowdcrafting.org provides the backend functionality for developing and hosting crowdsourcing applications, which includes generating and presenting tasks for users to complete and the collection and storage of generated data.

Prior to starting the project, users are presented with participation instructions and objectives. These instructions explain how to navigate the application, how to outline potential landfills and how to submit answers. Most importantly, the instructions provide example landfill images to demonstrate how to visually identify a landfill. Figure 2 shows the six landfill images manually selected as examples to guide participants. These landfills were determined as representative landfill images because of their common features including likeness in color, barren land cover, being distinctly man-made, sharp contrast to surrounding areas and exhibit concentric rings that indicate layering.

Upon completing the instructions, users are presented with an online interactive map and must locate potential landfills based on previously identified coordinates from the EPA ECHO database. Using Bing maps, users can navigate and explore the area and zoom in on specific locations to examine an area in detail. If a landfill is identified, users are instructed to outline the landfill with the provided drawing tools. Users are also given the option to skip the task if no landfill is found. To aid the user, additional information about the landfill is provided below the map including the facility name, address and state. Once a user has submitted their answer, a new task is randomly selected and presented to the user. Each task must be answered by10 unique users before it is determined as completed.

For each task, users can draw multiple geometries, edit their entries and estimate their confidence level prior to submitting the response. After a geometry is drawn, the total area of the polygon is calculated and displayed to the user while a second calculation converts the area from meters into the equivalent number of football field lengths to provide the user a more comprehensible measure of

***Figure 2.** Example landfill images shown to users prior to starting the project. Images were taken from Google Maps.*

the landfill's area. User-generated data is captured in GEOJSON format and results are immediately stored and made available by the Crowdcrafting.org backend.

Initial geospatial information about landfill locations was obtained from EPA ECHO and used as a starting point for participants to begin their landfill search. Landfills in the ECHO database were identified by using the Standard Industrial Code 4953 (Refuse Systems) and the North American Industry Classification System (NAICS) code 562212 (Solid Waste Landfill). Following the data export, further processing was necessary to remove duplicate entries, entries without geographic information and non-landfill entries. The final dataset comprised 1,235 entries representing potential landfills. Each entry contained a facility name, street address, latitude, longitude, and the number of days since last inspection. Manual verification of several potential landfill sites was performed to ensure projection accuracy.

3. INITIAL OUTCOMES

Participation in this crowdsourcing project highlights several learning opportunities both online and offline. The capacity for Landfill Hunter to create offline collaborative experiences was demonstrated during EcoHack 2014. EcoHack was a weekend-long event that took place in New York City and brought together participants with diverse backgrounds to explore the natural environment through data and technology. The event is designed to encourage collaboration and idea sharing to extend existing research and develop new projects related to the topic of nature and technology. Selected projects were presented to participants at the start of the weekend followed by the formation of groups to begin exploring and developing new ideas over the remainder of the weekend.

A group of 15 volunteers began to work with the Landfill Hunter project. This collaboration started by completing tasks in order to contribute data to the project and evolved into developing similar landfill-themed sub-projects. The result of this collaboration was the development and launch of a project titled Landfill Club. The project was initially designed to encourage people to think about where their trash goes and evolved into an online space for sharing information about landfills. The aim of this online space was to develop a community by connecting residents who share the experience of living in close proximity to a landfill. The space was not only created to facilitate information sharing for the purpose of increasing awareness about the existing challenges and struggles, but also to encourage and enable these communities to share experiences, solutions and strategies towards improvement. To develop this idea, the group launched a website to collect, analyze and present data about landfills[3]. This site organized existing information about landfills and showcased a variety of creative landfill visualizations. For example, the group juxtaposed the geospatial data from Landfill Hunter to compare landfill shapes and sizes and to potentially identify geometric patterns in the data. Other visualizations explored mapping the distribution of landfills across the US and comparing EPA landfill inspection rates across different states.

The experience of EcoHack demonstrates the project's ability to stimulate participant learning and creativity at many levels. The organic formation of an offline group who extended and further explored the theme of landfills, suggests that encounters and participation in Landfill Hunter can stimulate interest and curiosity in the subject matter beyond the online experience. Participants not only identified alternative landfill challenges, but collaboratively devised and implemented creative solutions for these challenges over the course of a weekend. The use of Landfill Hunter data for visualization and analysis furthermore demonstrates participant initiative, desire for further discovery, and a creative ability to convey information in a meaningful way.

3.1. **Data Contributions**

To date, participants have completed 15% of the project, contributing a total of 1,024 unique spatial geometries. A total of 729 landfills have been identified after removing outliers and combining user responses. Of the 729 user-identified landfills, 30% have been identified by multiple users as indicated by an overlapping geometry.

Figure 3 demonstrates an example task response after aggregation and shows the diversity of potential answers. In this case, the majority of geometries overlap the same area, while three other smaller non-overlapping geometries have been identified nearby. The overlapping geometries clearly show user agreement about the location of a landfill, albeit with variations in the exact border definition. The smaller geometries, though non-overlapping, could potentially represent smaller landfills and are therefore also included in the results. This approach allows for users to identify potential landfills that others may have missed. Figure 3B shows the user generated outlines on Google Maps for verification of accuracy.

Landfill land area was aggregated per landfill and for all identified landfills. Based on user identified landfills, the average landfill area is approximately $808m^2$ and the cumulative land area of landfills in the US is $576km^2$. This estimate is based on the 729 landfills identified by users, which represents approximately 60% of the landfills from the EPA Echo database and only 40% of the stated 1908

[3] http://landfill-club.herokuapp.com/, https://titanpad.com/8efVBMrPTe

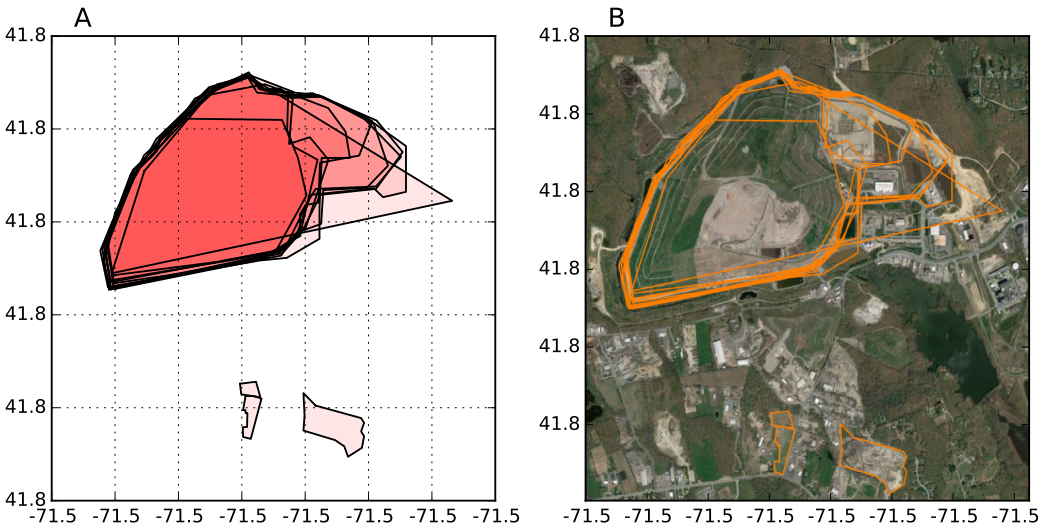

Figure 3. Example user responses aggregated by task. Fig 3A highlights user ability to identify similar landfill definitions while Fig 3B shows the results plotted with Google Maps.

total landfills in the country. Using the average landfill area and the EPA's stated number of landfills, the total land area of all landfills in the US is estimated to be 1,541km^2. This area is approximately twice the size of New York City whose land area is 709km^2.

4. PROJECT CHALLENGES AND LIMITATIONS

While Landfill Hunter demonstrates potential learning through online crowdsourcing, the project also faces several limitations. A key challenge for the project is the inability to validate user responses with "ground truth" data. As previously mentioned, the only available source of data about specific landfill locations and size is the EPA ECHO data. As a result, the accuracy of user-generated data is based entirely on the ability and collective intelligence of participants to identify and outline landfill locations.

Another significant challenge for the project is related to incentives and user motivation. Indeed, Landfill Hunter provides no extrinsic incentive to engage users beyond initial exploration of the project and largely assumes an intrinsic participant motivation. Exacerbating this issue, significant time and effort is required of the user in order to investigate the map, identify landfills, provide an outline of the landfill and submit the results. The high level of effort demanded from the user makes contributing to the project challenging and raises the barrier for participation (Dittus et al., 2016). To fully explore the potential of Landfill Hunter's methodology, significant evaluation of user motivation and user experience is needed.

5. CONCLUSION AND FUTURE WORK

Landfill Hunter is an online crowdsourcing project that addresses the intersection of public involvement in waste research and access to reliable information about landfills. The project creates a unique opportunity for citizens to explore nearby and distant landfills by analyzing existing data, contributing geospatial information and exploring high-resolution maps. The outcomes of participation in this project include experiential learning, generation of publicly available data and the potential to generate creative and collaborative offline experiences.

Several areas also exist for future work. To extend the existing project, critical analysis of participant motivation is needed. This includes developing appropriate incentives and rewards for participation as well as identifying and soliciting participation from specific interest groups who may directly benefit from the collection and analysis of the data. These groups may include local activist or environmental monitoring groups as well as other online based groups such as the Open Street Map community who may take interest in the project for its potential to contribute geospatial information. This type of small and targeted effort could greatly increase analytical capabilities of the project. Gamification is another possibility to enhance user motivation and has shown to be an important factor in increasing participation and maintaining long-term engagement (Iacovides et al., 2013; Jennett and Cox, 2014).

Other possibilities to determine and collect data about landfills could also be explored. For example, other online tools such as Google Terrain view may offer opportunities to explore and identify landfills in alternative ways. Similarly, the project could be used to develop a landfill health index based on a combination of existing EPA data and citizen generated data that extends beyond geospatial information to collecting information about local communities including socioeconomic and demographic information to identify and determine patterns in landfill activity.

Ultimately this research presents an opportunity to collect citizen-generated data about landfills to learn about the impact of landfills through participation. As explored with the subproject Landfill Club, the potential for local communities to engage in data collection about nearby landfills can lay the foundation for not only greater understanding of the geospatial presence of landfills in the US, but also to create a more open and transparent waste management system with the potential to reduce the negative social and environmental impacts of waste collection.

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