Participatory Infrastructure Monitoring: Design Factors and Limitations of Accountability Technologies

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Abstract

This dissertation investigates practices of participatory infrastructure monitoring and their implications for the governance of urban infrastructure services. By introducing the concept of infrastructure legibility, the three essays of this dissertation investigate ways to make waste systems and their governance more legible: its formal structure, its informal practices, interactions between the user and the provider, the individual and the system.

The first essay presents an analysis of the collection and transportation of Municipal Solid Waste and Recycling based on the electronic tracking of individual garbage items. It estimates the extent to which transportation diminishes the benefits of recycling and investigates how predictable the final fate of a discarded object is depending on its material characteristics and the place where it was thrown away. The findings show that the impact of transportation is under-estimated especially in the case of electronic and household hazardous waste. Furthermore, the collection mechanism assumes a decisive role in this respect. The essay concludes with discussing potentials and limits of active location sensing for making waste systems more legible and accountable.

The second essay investigates data collection methodologies for recycling cooperatives in Brazil, answering the following questions: how do waste picker cooperatives and associations respond to data reporting requirements from local governments and companies? In addition, how can available location-based technologies support data management and organization of these recycling cooperatives and associations? Based on the methodology of Participatory Design, the study evaluates technologies for data reporting and the organization of waste picker cooperatives.

Using data from citizen feedback systems operating in the larger Boston area, the third essay investigates the role of design in shaping the interaction between the citizens and the city. It investigates the following questions: Which assumptions about the users are embedded in design of existing feedback systems? What motivates users to participate, and how do the systems' design choices correspond with these motivations? By what mechanisms do these systems facilitate and constrain the interaction between citizen and city? The results show that the design differences of feedback systems are associated with different subjects and stated motivations in citizen reports.

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Abbreviations

MSW – Municipal Solid Waste

HHW – Household Hazardous Wastes

MRW – Moderate Risk Wastes

RCRA – Resource Conservation and Recovery Act

EPA – U.S. Environmental Protection Agency

LCA – Life-Cycle Assessment

WARM - Waste Reduction Model by the U.S. EPA

WEEE – Waste Electrical and Electronic Equipment

MRF – Material Recovery Facility

RFID – Radio Frequency Identification

CFL – Compact Fluorescent Light Bulbs

CRT – Cathode Ray Tube

GPS – Global Positioning System

EPR - Extended Producer Responsibility

NPSW – National Policy on Solid Waste (in Portuguese PNRS - Política Nacional de Resíduos Sólidos)

MNCR - Movimento Nacional dos Catadores de Materiais Recicláveis (National Movement of Wastepickers)

CRM system – Constituent Relationship Management system

HCI – Human-Computer Interaction

CCN – CitizensConnect (Product name)

SCF – SeeClickFix (Product name)

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Introduction – participatory monitoring technologies for infrastructure governance

In *Seeing like a State*, James C. Scott identifies legibility as a central issue of governance. In order to govern, a modern state has to know where people and things are; "to make a society legible, to arrange the population in ways that simplified the classic state functions of taxation, conscription, and prevention of rebellion (Scott 1999, 2)." His concept of legibility encompasses such diverse things as the institution and registration of family names, standardized measures of distance and weight, the introduction of cadastral maps, and scientific forestry – all of these measures are designed to make the territory of a state, its economic output and its population governable (Figure 1).

This legibility is not just descriptive, but also prescriptive by implementing an abstract universal norm. Establishing legibility therefore becomes an authoritarian technique, a variation of Foucault's idea of coercion through observation (Foucault 1977, 170–171). Scott's conceptualization of legibility is a legibility from above, which seeks to reduce the complexities of any real society. This legibility favors the privileged outsider, who otherwise would not be able to 'read' an unfamiliar place or environment, while it is unnecessary for locals, who possess local knowledge and their own conventions for measurement. For them, illegibility becomes a means to resist outside control and preserve local autonomy (Scott 1999, 53).

Scott's conceptualization of legibility, however, fails to acknowledge that there are also situations, in which local knowledge is not enough to make sense of a condition that transcends the local realm. In this case, local actors need to establish what could be called "legibility from below."

Legibility of Social Groups, Institutions, and Practices

	Illegible	Legible
Settlements	• Temporary encampments of hunter-gatherers, nomads, slash-and-burn cultivators, pioneers, and gypsies	• Permanent villages, estates, and plantations of sedentary peoples
	• Unplanned cities and neighborhoods: Bruges in 1500, medina of Damascus, Faubourg Saint-Antoine, Paris, in 1800	• Planned grid cities and neighborhoods: Brasília, Chicago
Economic units	• Small property, petite bourgeoisie	• Large property
	• Small peasant farms	• Large farms
	• Artisanal production	• Factories (proletariat)
	• Small shops	• Large commercial establishments
	• Informal economy, "off the books"	• Formal economy, "on the books"
Property regimes	• Open commons, communal property	• Collective farms
	• Private property	• State property
	• Local records	• National cadastral survey
Technical and resource organizations		
Water	• Local customary use, local irrigation societies	• Centralized dam, irrigation control
Transportation	• Decentralized webs and networks	• Centralized hubs
Energy	• Cow pats and brushwood gathered locally or local electric generating stations	• Large generating stations in urban centers
Identification	• Unregulated local naming customs	• Permanent patronyms
	• No state documentation of citizens	• National system of identification cards, documents, or passports

Figure 1 James C. Scott's characterization of the legibility of governance (1999, 220).

Perhaps most popularly connected to the notion of legibility, Kevin Lynch's work on urban form was shaped by the idea that a good city is a city that is legible for its inhabitants. People would strongly prefer environments that facilitate orientation, conveying a sense of where they are in the city. Lynch consequently defined legibility as "the ease with which its part can be recognized and can be organized into a coherent pattern" (Lynch 1960, 2–3) and later as "the degree to which the inhabitants of a settlement are able to communicate accurately to each other via its symbolic physical features" (Lynch 1984, 139). In *The Image of the City*, Lynch identified five elements that constitute the syntax of the mental image of an environment: *paths*, *edges*, *districts*, *nodes*, and *landmarks*. *Paths* and *edges* are linear elements; paths being the channels of an observer's movement, and edges other articulated elements such as walls or coasts. *Districts* are sections of the city that have their own character, while *nodes* are focal points of activity such as intersections of multiple paths. Finally, *landmarks* are distinctive features in the city that are commonly used for orientation (Lynch 1960, 48). It is important to note that the role of these elements is contextual and local rather than absolute and universal – their significance lies in their ability to align and integrate different parts of the city into a coherent mental image. In this sense, also obstacles, barriers, and borders play an important role in establishing a concise mental image of a place. Unlike Scott's use of the term, Kevin Lynch's conceptualization of legibility is a legibility from below, constructed from the experience of an individual observer rather than derived from the geometry of urban form. Lynch noted that his main intention was to encourage planners to pay more attention to the inhabitants and their perceptions (Lynch, in Banerjee and Southworth 1995, 251).

By invoking legibility, both Scott and Lynch use the metaphor of the city as a text, which can more generally be understood as discrete symbolic information. This metaphor is especially pertinent for urban infrastructural systems, which encompass physical and informational, social and technical dimensions. Considering infrastructural systems as a text that can be read, we see that the readers of these data are represented different actors, as is their perspective - above, below, inside or outside the system. The central idea guiding this dissertation is that the legibility of infrastructure is a crucial element for its governance and for mediating the relationship between the individual and the system. Such a concept of infrastructure legibility could stand for the degree to which the features of an infrastructural system can be recognized by its users and governors with regard to the structure and activities of the system as well as its governance – the presence of participants in the system, their actions, decisions and their consequences. Infrastructure legibility therefore encompasses physical qualities, such as the color-coding scheme of waste containers and the information printed on it, but also informational aspects, such as key performance indicators collected by municipalities, real-time information feeds by from environmental sensors deployed by public or private initiatives.

The legibility of infrastructure governance

The three essays of this dissertation explore ways to make waste infrastructure and their governance more legible: its formal structure, its informal practices, interactions between the user and the provider, the individual and the system.

Most literature concerned with the study of infrastructural systems assumes the perspective of the system builders and infrastructure governors, embodying Scott's perspective on legibility from above. From the perspective of the individual user, these systems are often experienced as invisible, either because their physical parts are hidden literally under the surfaces of the city, or because the users have learned take the system for granted and do not notice it anymore. Mark Weiser, the pioneer of ubiquitous computing, observed: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser 1991, 94). Invisibility is therefore a desired quality that facilitates effortless interaction with a system.

However, the arrangement of 'legibility from above, invisibility from below' is problematic in several ways. First, the view from above is often incomplete; it does not reach the bottom: infrastructures such as the waste system are characterized by a lack of quality data about its structure, processes, and performance. Second, the nature of infrastructure services is changing; they become less invisible and require an increasing level of user involvement, voluntarily or involuntarily. I argue that we need a new theoretical perspective on infrastructures, that incorporates the view from below and the multiple dependencies that are active on that level. We also need new technologies that provide us with a fine-grained picture from this perspective, technologies that help us to observe processes that are otherwise not accessible from the perspective of the infrastructure governor. We also need to figure out the best way to involve the user. Taken together, we need to conceptualize infrastructure governance as an interactive accomplishment of users, technology and its representations, and city.

The Oxford English Dictionary defines infrastructure as "the subordinate parts of an undertaking; substructure, foundation; specifically the permanent installations forming a basis for military operations, as airfields, naval bases, training establishments, etc." [1] Reflecting this broad and loose definition, the term infrastructure has been used to describe such diverse things as streets and bridges, educational services, software networks, laws and standards, or social organizations. Due to the lack of a more concise definition, the term is usually narrowed by enumerating examples illustrating which kinds of systems are meant, by focusing on a disciplinary context, or by defining characteristics of infrastructural systems that apply to a specific context. Planning and engineering disciplines frequently distinguish between "hard" infrastructure, referring to physical structures such as roads, airports, or sewer networks, and "soft" infrastructure, encompassing institutions such as health, education and social services. Civil engineers further distinguishes between infrastructure, utility, and service, in which infrastructure refers to the physical structure that is operated and maintained by a utility company in order to provide a service such as electricity or waste collection.

The historian Thomas P. Hughes framed urban infrastructure as a Large Technological System (LTS), describing a complex socio-technical system that encompasses physical, organizational, and other associated or facilitating components such as regulatory laws or scientific theories. Hughes explains that the construction of such a system is never monolithic, but involves the coordination among a diverse group of stakeholders and experts. Furthermore, a Large Technological System is a dynamic system. In its constant evolution, all of its components interact with each other and co-evolve: when one

[1] "infrastructure, n.". OED Online. December 2012. Oxford University Press. http://www.oed.com/view/Entry/95624 (accessed December 19, 2012).

component changes, such as the introduction of a new technology or regulation, the other components adapt accordingly (1987).

Infrastructure has also been defined from an economic perspective. Urban Infrastructure requires a long-term strategic decision to invest, since the payback for the system-builders will not be immediate, and the system's long pay-off period usually benefits somebody else. Therefore, Morag Torrance argues that infrastructure should foremost be understood as a class of financial assets. The reconfiguration of urban landscapes resulting from infrastructure privatization and globalization is best explained through the forces of the financial industry, rather than the physical purpose or organizational nature of infrastructure (Torrance 2009). The economist Remy Prud'homme defines infrastructure through six characteristics, including its role as a capital good that is not consumed directly, is lumpy as opposed to incremental in its revenue, long-lasting, space-specific, is associated with market failures, and usually consumed by both households and enterprises (Prud'homme 2005).

Both perspectives have in common that they conceptualize infrastructure primarily from the standpoint of the system builders, while the users of these systems remain absent. This has been criticized by a number of authors who in response offered alternative conceptualizations of infrastructure from the perspective of the users. The anthropologists Susan Star and Karen Ruhleder describe infrastructure as an emergent activity or relationship rather than a physical structure, holding: "infrastructure is a fundamentally relational concept. It becomes infrastructure in relation to organized practices" (1996). They define infrastructure through eight characteristics, including transparency, embeddedness, the fact that infrastructure has to be learned as part of membership, links with conventions of practice and embodies standards (Star and Ruhleder 1996).

In economics, Brett Frischmann presents a demand-side theory of the "infrastructure commons" that focuses on the social and economic value of infrastructure for its users. Frischmann hypothesizes that the social returns of an infrastructure investment exceed the private return and argues for a commons-based management of infrastructure as a public good that is non-rivalrously consumed (Frischmann 2012, 61). Finally, the concept of *Inverse Infrastructure* focuses on infrastructures, which are unplanned and informal. Inverse Infrastructures are characterized as user-driven, self-organized, and decentralized (Egyedi and Mehos 2012). The notion of a user-driven inverse infrastructure can be illustrated by a number of recent examples and practices involving crowd-sourced and mediated forms of organization. Open-source software development is an often-cited example of an inverse infrastructure, whose modes of operation stands in contrast with conventional software development management practices (Raymond 1999). It is often overlooked that the vast majority of tasks in this domain do not concern the production of new code, but are rather "infrastructural" in nature, including the maintenance of released versions, resolution of technical dependencies and most importantly, bug tracking. The tools and practices developed by the Open Source community for coordinating a crowd of contributors over the web have recently been adapted in domains unrelated to software development.

Infrastructural inversion of public services

The literature of Socio-Technical Systems often characterizes infrastructure as a black box – a system that is sufficiently described in terms of its inputs and outputs, without requiring any knowledge of its inner workings. A black box "contains that which no longer needs to be considered, those things whose contents have become a matter of indifference" and therefore has become stable and unquestioned (Callon and Latour 1981, 285).

It can, however, be argued that urban infrastructures such as highways, sewer networks or the waste system have recently become less invisible, and that they require an increasing amount of attention and participation from their users. This development, theorized by Geoffrey Bowker as a process of *Infrastructural Inversion* (1994), can be attributed to a number of reasons.

Urban infrastructure has undergone fundamental change during the past three decades, manifested the increasing privatization and unbundling of infrastructure services in industrialized nations (Steve Graham and Marvin 2001, 84). In many cases, urban services are no longer owned and operated by the public sector, but by a range of private actors, resulting in a spatially fragmented and socially segregated landscape of service provision. On the most basic level, this fragmentation forces the consumer to get more invested in the selection of a service provider, and scrutinize different service alternatives that are often difficult to compare. Secondly, urban infrastructure has become more visible because of its increasingly precarious state. The physical condition of urban infrastructure networks in the United States is widely perceived as deteriorating, due to the generally dire financial situation of municipalities, states, and national governments. Power blackouts and other system failures make infrastructure more visible – as the anthropologist Susan Leigh Star notes, infrastructure "becomes visible upon breakdown" (Star and Ruhleder 1996, 5). The urban infrastructures in many cities of the Global South are characterized by frequent disruption and inequality of service provision. As a necessary result, these services are more participatory – requiring the active involvement, improvisation and informal coping strategies from its users (Stephen Graham 2009, 144).

As a third aspect, the previously clear-cut distinction between service provider and consumer is becoming increasingly blurry. Private households operating their own photovoltaic cell-arrays become to a certain extent service providers themselves. Smart-grid infrastructure shifts a significant part of the system's operational logic to the side of the user, who in return becomes a provider of valuable usage data. While the smart meter might operate unnoticed and transparently, there are also cases where the use of infrastructural services has become more demanding for the user. For example, compliance with frequently changing recycling and waste regulations requires a significant amount of knowledge about waste management practices. As a result, everyday decisions, such as choosing the right bin for a piece of garbage requires conscious reflection that cannot be automatized, making the process more visible to the user.

Finally, disputes about infrastructure provision have become more present in public discourse. Citizens in industrialized as well as emerging countries have become more alerted to issues of environmental justice and accountability, and want to make sure that infrastructures are managed in a responsible way.

All of these aspects indicate that the traditional model of infrastructure as a system involving a central service provider such as the local government on the one side, and a population of passive consumers on the other, is less applicable today than it was in the past. Even without considering new technologies and connected practices, traditional urban infrastructural services such as waste collection, electricity, and urban maintenance have once again moved to the foreground of attention.

Figure 2 Statistical Exhibits in the Municipal Parade by the Employees of the City of New York, 1913. "The Health Department, in particular, made excellent use of graphic methods, showing in most convincing manner how the death rate is being reduced by modern methods of sanitation and nursing." (Brinton 1914, 342)

The legibility of waste systems

Waste Infrastructures embody many of the issues discussed in the previous sections. They are frequently characterized as invisible, as long as one does not live right next to a treatment facility, a landfill, or other undesirable locations. Despite frequent educational campaigns for promoting proper recycling practices, the users of waste systems rarely receive information about where their waste and recyclables are taken, or what happens after the first transfer station. But also professionals or public works departments do not always have complete information about the systems they oversee. One of the fundamental challenges the waste management sector faces is a lack of information and quality data. This includes the fact that a substantial amount of Municipal Solid Waste is not reported in the U.S. national statistics, due to multiple exemptions and a lack of commonly shared definitions. Furthermore, uncertainties about the roles of federal, state and local governments result in a lack of even and predictable enforcement regulations and standards (Kreith and Tchobanoglous 2002). Waste exports are another white spot on the map: since the US did not ratify the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the export of hazardous wastes legal and largely undocumented (J. Puckett et al. 2002, 6).

Despite, or because of this lack of representation and data, the discourse around waste systems is characterized by a multitude of different perspectives with often mutually exclusive interests: including public health, system efficiency, aesthetics and nuisances, environmental conservation, and environmental justice. Most of these perspectives have played an important role in the historical development of sanitation infrastructures (Melosi 2004); it is therefore instructive to briefly review the historical context from which they evolved.

The role of waste and sanitation infrastructures for the genesis of the modern urban planning discipline can hardly be overestimated. The explosive growth of cities during the industrial revolution was accompanied by frequent disease outbreaks including typhoid and cholera. In the mid-19th century, there was a consensus that unsanitary conditions, partly caused by the breakdown of the traditional disposal system of cesspools and privy-vaults, and disease are causally connected. According to the miasma theory popular at the time, the decomposition of organic waste produces toxic fumes that spread in the city and were the cause of disease outbreaks. While the miasmatic theory has been refuted, it helped establishing consensus about the need for a public stewardship and centralized planning (Tarr 1996, 209).

The beginnings of modern sanitation systems were therefore dominated by the public health perspective. Centralized, municipal responsibility for waste and sanitation led to a new perspective shaping the waste system embodied in the profession of the sanitation engineer. Consequently, waste removal became primarily an engineering problem, most efficiently addressed in a centralized system. Municipal waste management was first realized in the US by New York's street commissioner George Waring. He provided comprehensive solutions for both garbage collection and sanitation that included centralized municipal infrastructures by his own design (Melosi 2004, 35). Waring introduced a comprehensive recycling system with mandatory source separation, increasing revenue by selling reusable material (Strasser 2000, 130).

While public health officials and engineers were concerned with disease control and efficient waste management, citizens became increasingly concerned with the aesthetic aspects of sanitation. Sanitary reform and the city beautiful movement – two main responses to the crises of the industrialized city – were intrinsically linked (Melosi 2004, 76). Since waste facilities are most prominent among locally unwanted land uses (LULUs), social forces ("not in my backyard") began to outweigh engineering considerations. As a result, waste streams tend to follow the path of least resistance, leading through neighborhoods of the poor and marginalized (Pellow, 2004). This unequal distribution of the burdens and health hazards of waste disposal led to rise of the Environmental Justice movement, documenting practices of environmental racism in the waste management sector (United Church of Christ 1987; Bullard 2000).

With the more recent privatization and globalization of waste management, the economic perspective on waste has again become more important. With growing waste transportation distances across states and continents, trade logistics and international agreements become a determining force shaping the waste system. As Porter notes, "transporting waste is trading waste. All trash is traded" (Porter 2002).

Each of these perspectives deals with a different aspect and generates different representations of the waste system. What is missing, however, is a shared representation of the waste system that enables further dialog between those perspectives.

Accountability mechanisms in infrastructure governance

Legibility from below concerns, primarily, the legibility of governance itself. As Andreas Schedler puts it: "the great difficulty lies in this: you must first enable the government to control the governed; and in the next place oblige it to control itself" (Schedler 1999, 13). Transparency measures such as Freedom of Information laws and Open Data policies are designed to prevent corruption by rendering governance legible to constituents and allowing them to evaluate government performance and corporate actions.

Accountability, a central element of what is considered good governance, is a relationship between two parties, in which one party is obliged to inform the other about their past or future actions and decisions, to justify these actions and accept sanctions in the case of violations (Schedler 1999, 17). Schedler identifies two central aspects: answerability and enforcement. Answerability involves the obligation of power holders to inform the public about their decisions by generating data, releasing information, and be prepared to answer questions from the public. Enforcement means the capacity to impose sanctions on public officials in case of violations (1999, 14). The relationship between citizens and public entities, or more general between a principal and a subordinate, has been characterized as vertical accountability. But also actors on the same level inside government institutions or in professional relationships are accountable to each other to prevent violations, consequently characterized as horizontal accountability (O'Donnel 1999, 17). A further distinction can be made between formal and informal channels of accountability. Formal channels of accountability include elections and legal enforcement mechanisms. If formal enforcement is not possible, accountability can be established through informal channels, by creating pressure through the media and using 'rude' tactics of naming and shaming (Hossain 2010).

However, in the case of the increasingly fragmented nature of contemporary urban service delivery, the flow of information cannot be neatly divided in vertical and horizontal modes of accountability. Urban services are determined by a large number of public and private actors who depend upon each other in complex ways, including municipalities, private companies such as waste haulers and recyclers, commercial customers and private citizens, watchdog organizations and federal regulators. Due to the wider distribution of control, formal instruments of vertical accountability are not always sufficient to establish transparency and prevent mismanagement.

A strategy to address this situation is to strengthen the involvement of the civil society into the governance of service delivery, therefore transforming the traditionally vertical relationship between individual and system into a more horizontal one. Social Accountability stands for community-driven approaches for keeping power-holders accountable (Joshi and Houtzager 2012; Malena, Forster, and Singh 2004), including and the involvement of citizens and citizen organizations in the oversight of services. The tasks of monitoring and data collection are therefore no longer limited to the state. While social accountability initiatives can be initiated by a public authority, they often operate from the bottom and are driven by the community itself.

Social accountability initiatives can take many forms: a city implementing feedback mechanisms for urban services, a grassroots initiative collecting data to support a desired policy change, or a development organization working with communities to prevent the misuse of funds by corrupt officials. The mechanisms of social accountability can be both formal and informal – operating through the judiciary, the political competition, or the "court of public opinion" facilitated by mass media and community organizing. Social accountability initiatives have a long tradition that predates the term, with the citizen-initiated investigation of the Love Canal Disaster being among the most prominent examples (Freudenberg and Steinsapir 1991).

A central problem for social accountability initiatives is the coordination among participants, for example to facilitate the systematic collection of evidence. In this context, digital information technologies can potentially play an important role. Accountability technologies (Diamond 2010, 77) stand for technological tools for addressing problems of coordination, data analysis and dissemination. Digital platforms have been used for example to document corruption or monitor elections.[2] A well-publicized example is the Ushahidi platform, which originated from an initiative to monitor violent incidents after Kenya's disputed presidential election of 2007 (Okolloh 2009).

The mechanisms by which accountability technologies achieve their goals are manifold and often convoluted, matching the ambiguity of the term accountability itself. One meaning of accountability is narrative: an explanation and justification of the issue at hand. The second meaning refers to the practice of book-keeping, systematic data collection and the provision of access to these data (Schedler 1999, 14). In order to be effective, accountability technologies have to interface at some point with formal mechanisms; social accountability initiatives depend on a system of governance that respects the role of the community. The notion of accountability acknowledges the fact that full transparency is not possible where humans make decisions, and is probably not desirable since it would

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[2] http://ipaidabribe.com

make it very difficult to make any decisions at all. Therefore, both top-down and bottom-up perspectives share common territory.

Participation in urban service provision and the changing role of the state

Social accountability is increasingly seen as a critical tool for improving urban service provision. It is often hypothesized that service providers can be held more effectively to account if the users and affected communities of their services are directly in monitoring and controlling these services (Cavill and Sohail 2004, 155). Social accountability could be a potential mechanism for preventing waste and fraud of public funds, making services more equitable by involving those who have otherwise no voice, promoting urban services to citizens as a public good, and increasing the efficiency of service delivery by utilizing citizen feedback. Such a model of service provision can be implemented in two different ways, described in the 2004 World Development Report as the short route and long route to accountability (World Bank 2004). The short route would direct connection between citizens and service provider; the long route connects provider and citizen indirectly via the public authority.

These approaches have to be seen against the backdrop of a fundamental shift of the role of the state in infrastructure governance. Until the 1960s, public authorities acted as a developer and provider of public infrastructure services, following what Steve Graham and Simon Marvin have called the integrated infrastructural ideal: the provision of uniform, standardized and ubiquitous access to infrastructural networks (2001, 84). By the late 1960s, the sanitation, electricity and transportation had been completed in most industrialized countries. The following decades were characterized by a departure from the integrated ideal and the consequent gradual withdrawal of the public hand from infrastructure provision.

The economic crises of the 1970s and changing political economies have weakened the role of the state and impeded the quality of urban service provision. Especially in developing countries, service provision has been chronically underfunded and not been able to keep up with the rate of urbanization. In the following decades, most municipalities have reacted by privatizing their infrastructural services and adapting a more business-oriented style of urban governance. During the 1980s and 90s, the paradigm of New Public Management (NPM) introduced a stronger market and customer-service orientation and the adaptation of private sector management techniques into the public sector (Drechsler 2009). However, these reforms were not as successful as initially hoped and the effectiveness of NPM has come under critique. Experiences from states and cities adapting NPM principles have raised equity concerns about exclusion due to uneven service provision, and have disappointed the initial economic expectations. Since the 2008, especially states and municipalities in Central Europe have started to assume a stronger role, began to gradually re-integrate and re-orient their services towards a shared public good, a concept sometimes termed the Neo-Weberian State (Drechsler 2009).

Civic technologies such as e-government platforms are often associated with the paradigm of New Public Management, mainly because of their emphasis on responsiveness, professionalization, and efficiency of service provision. New York's 311 call-center and many other initiatives for collecting real-time feedback and incident reports relevant for urban maintenance such as graffiti, broken streetlights or potholes underline this idea of the citizen as a customer. During the past years, the tech-community has embraced the idea self-organized urban infrastructure services, entirely driven and maintained by the users through digital technology. Using the presumably de-centralized nature of the Internet as a metaphor, the role of public authorities in the provision of infrastructure services is increasingly called into question, suggesting that many of these public responsibilities could be provided more efficiently by a decentralized network of amateurs (Borden 2011).

While all of these examples can be seen in line with the neo-liberal underpinnings of NPM, this characterization is not always justified. Transparency and Open Data initiatives go beyond the scope of NPM (Dunleavy et al. 2006), and are driven by the idea of data as a public good. Contrary to the goals of

NPM, these systems are neither inexpensive in their maintenance, nor provide any immediate economic benefit for the municipality. It is hoped, however, that they will provide the basic infrastructure for a new community of entrepreneurs operating in the civic sphere. In these projects, the state assumes again a stronger and more active role as developer and provider of a basic infrastructure than the NPM paradigm would allow for.

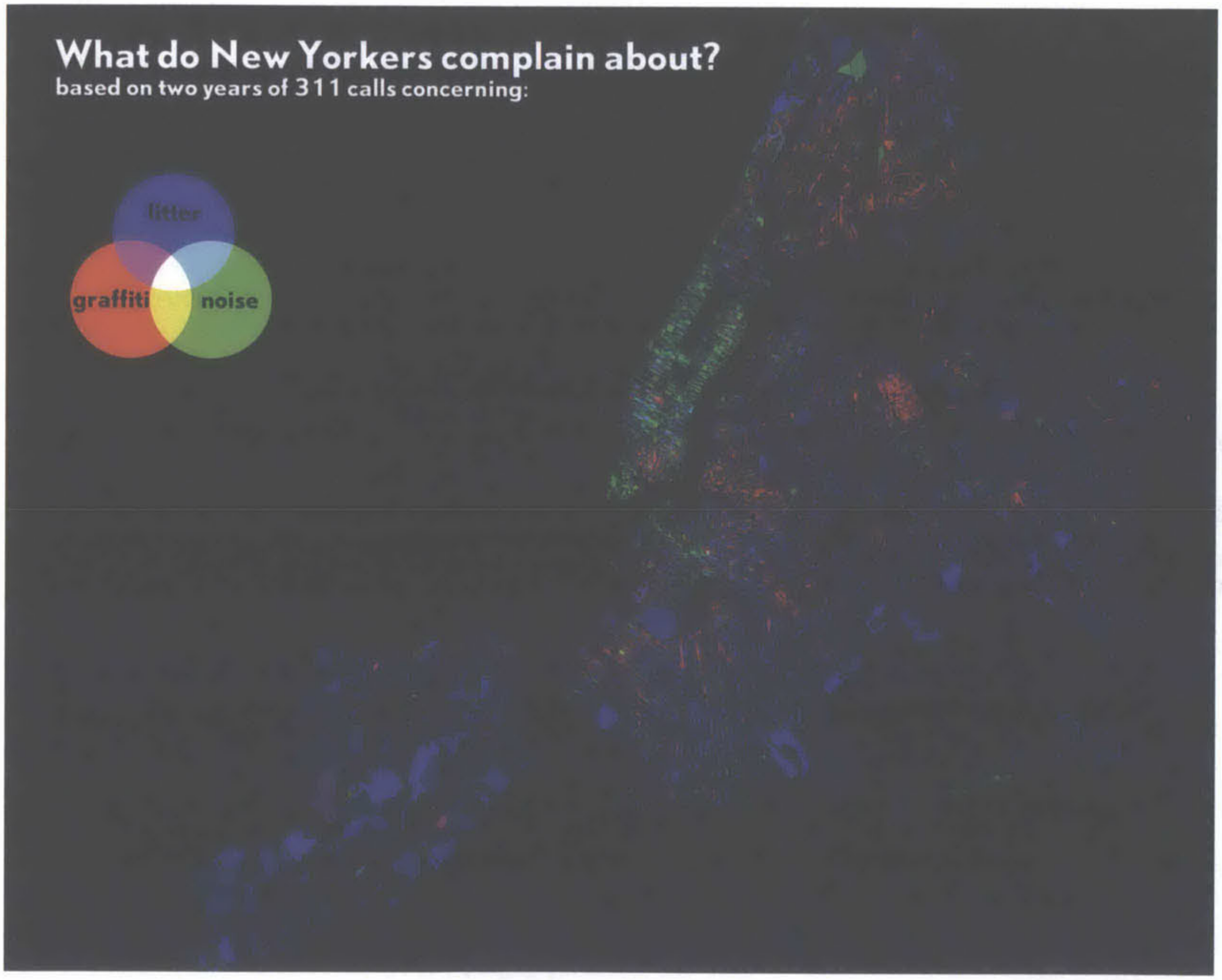

Figure 3 Map showing the spatial distribution of citizen complaints via New York's 311 helpline with respect to three different complaint types: noise, graffiti and litter. Each complaint type is associated with a base color of the RGB color space, allowing an estimation of the proportional distribution of each complaint type by comparing the resulting colors in different parts of the city. Source: https://nycopendata.socrata.com, visualization by the author.

Forms of participation in service provision and their criticisms

Participation as Compliance

Participation of citizens in urban services can happen in various degrees. On the most elementary level, it means using the system in a way that is aligned with the intentions of the system designers. The idea that such compliance requires additional educational efforts is not new. In the 1890s, George E. Waring, the designer of New York's first comprehensive sanitation and garbage system, was therefore not only concerned with the technical aspects of his waste water system, but also with the promotion of the sanitary idea. Waring designed the eye-catching white uniforms of the street sweepers, New York's "White Wings"; he also organized juvenile street cleaning leagues, singing songs composed to promote cleanliness (Melosi 2004, 82). Educational campaigns for establishing awareness and participation can be traced back to the "Keep Our City Clean" campaigns of the City Beautiful movement, and were continued in the form of anti-litter campaigns throughout the 20th century, using slogans such as "Don't Litter" or "Recycle More" (Melosi 2004; Hoy 1996).

Participation as Feedback

Beyond compliance, user participation is also a means for gathering feedback, either as "passive source of information concerning demand and user satisfaction" or as "active suppliers of relevant information about the levels and quality of service delivery" (Schubeler 1996, 74). Opinion polls, citizen report cards, or community scorecards are widespread tools for assessing the quality of urban service provision for collecting anonymous feedback in a one-way mode of communication. An example is New York's "Project Scorecard," which since the 1970s uses citizen surveys to gauge the street cleanliness (Melosi 2004, 252). In other models, users have a more active role. Participatory Monitoring is a social accountability approach involving constituents in monitoring the quality of service provision that has recently played an increasingly important role in international development projects (Estrella and

Gaventa 1998). Beyond measuring performance, citizen feedback allows for a more targeted service provision based on the needs of the users (Schubeler 1996, 8).

Participation as oversight and control

Naturally, the engagement of citizens in oversight of service provision is not always the main interest of providers. Citizen oversight might be implemented for several reasons. The Municipality might want to improve user satisfaction and solicit support for monitoring a private service contractor. A development agency might want to prevent waste and corruption through local actors involved in the service provision, and empower disadvantaged communities who might receive inferior service otherwise. While the genuineness of such forms 'participation by decree' is sometimes questioned, users who feel that they do not receive adequate service quality might also launch watchdog initiatives themselves. Citizen oversight might be implemented in various forms, for example through integration into e-governance platforms (Verplanke et al. 2010).

Participation as Co-governance and Self-organization

Involving users directly in the operation of service provision goes beyond the traditional understanding of urban services. Nevertheless, a number of examples exist. Non-profit organizations frequently provide infrastructural services based on the work of volunteers. The Appalachian Trail Conservancy maintains for example an extensive network of hiking trails entirely though the labor of over 6000 volunteers.[3] Under the term "Big Society," the British government under David Cameron has sketched out an agenda of promoting volunteering for the provision of public services. The policy includes a "right to challenge" that would allow community groups to bid for public service contracts (Hudson 2011, 19). In international development, Community-Based Organizations for service provision in environments with scarce resources have shown some success, with citizens being involved in initiating and executing

[3] http://www.appalachiantrail.org/get-involved/volunteer

infrastructure projects of which they will be the beneficiaries (Ibem 2009, 130). Examples also exist for urban services initiated and are operated by groups of individuals, such as citizen-driven collection of waste paper in the Netherlands (De Jong and Mulder 2012)

Criticisms of user participation in service provision

Service provision relying on citizen feedback can reinforce inequality

A number of studies have shown that feedback mechanisms and grievance systems, intended to improve service provision for the poor, can have the opposite effect. Martínez et al. have observed that communities living in impoverished areas complain less than the residents of more wealthy and better-serviced areas (Martínez, Pfeffer, and van Dijk 2009). These differences can be explained through different attitudes and levels of trust towards the local government.

"Short Route" participatory governance models are often ineffective

In their comparative study of social accountability initiatives for improving service quality, Cavil and Sohail have found most of the initiatives failed to improve the services. Especially the "short route" between users and providers were experienced to be ineffective by the users, who often felt that their complaints were ignored. The "long route" of social accountability, for example approaching politicians with complaints about service provision or initiating grassroots campaigns, yielded better results (Cavill and Sohail 2004).

Successful examples of self-organization can seldom be generalized

The critical issue is not the development of a new infrastructure, but sustaining and maintaining it over an extended period. In that respect, many of the systems discussed by Egyedi and Mehos are difficult to compare: an online community is very different from running a waste collection system in terms of costs and incentives for participation. While also the online platforms used by Open Source Developer communities do require a significant amount of regular maintenance, they are first a knowledge community thriving from the constant addition of material. The motivations of volunteers running a waste collection system on the other hand might be very different.

Concerns about amateurism and data quality

One frequent criticism about amateur data collection concerns the quality and credibility of the information they produce (Keen 2007). However, it cannot be taken for granted that data collected by an official source is always reliable. A recent study on street maintenance in New York City finds a high correlation between citizen generated data and reliable objective measures, independently from socio-economic factors (Van Ryzin, Immerwahr, and Altman 2008). Coleman et al. have shown that the concern of missing expertise can be addressed by differentiating between different types of contributors, ranging from the casual contributor to the fully committed "expert amateur." Data quality can be managed, if it is understood which kind of users engage in the system (D. Coleman, Sabone, and Nkhwanana 2010).

The structural limits of volunteer-generated data are more difficult to address. The data are non-probabilistic, subject to various systematic biases. The relationship between the users and creators in online media is generally highly asymmetrical (Rafaeli and Ariel 2008). Jacob Nielsen coined the term of the "90-9-1 rule", meaning that 90% of social media users consume, but don't contribute, 9% contribute occasionally, and only 1% of the users are active on a regular basis (Nielsen 2006). In the case of Wikipedia, 2.5% of the users are responsible for 80% of the total content (Rafaeli and Ariel 2008, 248). These figures seem to indicate a universal structural property: similar to many other phenomena related to human interaction, the frequency of contributing in the population follows a power law distribution, also known as Zipf's Law (Adamic and Huberman 2002). In the context of infrastructure management, such a distribution poses a hard structural limit, highlighting a conflict between the requirement for a homogeneous, and reliable service provision and the uneven nature of user participation.

The value of participation remains too often unquestioned

The most fundamental critiques concern the concept of participation itself. The value of participation is often taken for granted as a means as well as a prerequisite for a just and inclusive society, to the point where participation became the "new grand narrative of development" (Cooke and Kothari 2001, 139). But participation is not always empowering, it can also be a burden. Peter Schubeler addresses this by asking: why should citizens living in neighborhoods that receive poor infrastructural services have to concern themselves with infrastructure management and support a local government that does not support them in return; especially when at the same time other neighborhoods of a higher socio-economic status receive a better service (1996, 32)? Citizen involvement can also become a burden for a local government, overemphasizing process over the outcome, especially for agencies that are already severely underfunded for its tasks for developing infrastructures (Schubeler 1996, 44).

Rhetoric of participation is often used to cover hidden agendas

A second critique addresses the rhetoric strategy of individualization – an attempt to shift the responsibility for systemic issues to the individual. Recycling campaigns frequently focus on the behavior of the individual without questioning the role of manufacturers of wasteful products and infrastructure providers (Maniates 2001). Recently, the "Big Society" initiative has also been accused of having a double agenda. Ostensibly, the program is about empowering communities and fostering social action, while promoting the idea that many public services, including youth and public health programs, could be replaced by volunteer organizations (Hudson 2011). However, the entailed cuts in public funding have caused the affected volunteer groups to largely reject the conservative embrace. Their argument that successful volunteerism requires nurturing from the government is backed by studies finding that less public spending also leads to a decline in volunteering (Penny 2012; Bartels, Cozzi, and Mantovan 2012).

Overview of the three essays

The three essays of this dissertation explore the potential roles and limitations of location-based technologies for monitoring and governing urban services (Table 1). Starting from the premise that digital augmentation of urban infrastructures and services opens new interaction channels, may facilitate self-organization and new forms of participation, they present three case studies of projects designed to make waste infrastructures and their governance more legible from the perspective of the user – by collecting data that provide insights into the system's formal structure, informal practices, and the interactions between the individual and the system. Since these interfaces mediate the interaction between the individual and the system, design becomes an important factor that is often overlooked. Each essay addresses the following overarching questions:

- **Infrastructure governance**: What are the implications of pervasive sensing technologies for the future of urban services and their governance?
- **Participation**: What modes of participation and interactions do these technologies afford?
- **Design Factors**: How does the design of technological interfaces shape these interactions?
- **Accountability**: How can the data generated by these systems help to make urban services more accountable?

Table 1 Overview of the essays

	Essay 1 – Putting matter in Place	Essay 2 – Tacit Arrangements	Essay 3 – Infrastructure Legibility
Legibility	of system structure and activity	of practices and organization	of governance and social presence
Locus of the observer	outside the system	inside the system	at the system boundary
Geography	Seattle / US	São Paulo, Recife / Brazil	Boston / US
Unit of analysis	Waste Item	Worker	Reported Issue
Investigated nexus	user – provider provider – provider	provider – city provider – provider	user – city
Focus of participation	monitoring	management	governance
Research Questions	RQ 1: To what extent can waste transportation diminish the benefits of recycling? RQ 2: To what extent is the final fate of a discarded item predictable through its material and the location where it was discarded? RQ 3: What are the implications and limits of active location sensing for the governance of waste infrastructure?	RQ 1: How do waste picker cooperatives and associations respond to data reporting requirements from local governments and companies? RQ 2: How can available location-based technologies improve the data management and coordination of these recycling cooperatives and associations?	RQ 1: Which assumptions about the users are embedded the design of online 311 platforms, and how are these assumptions translated into design features? RQ 2: Why do users submit reports, and how do the system's design features correspond with these motivations? RQ 3: By what mechanisms and design principles do existing systems facilitate and constrain the interaction between citizen and city?
Methods	Participatory sensing / quant. Analysis / semi-structured interviews	Participatory Design / semi-structured interviews	Content analysis w. open coding / spatial analysis
Findings & Policy Implications	• E-waste and HHW items report longest traces, in some cases, transport neutralizing energy savings of recycling (based on WARM model) • Problematic aspects of mail-back / take-back programs: longest transportation distances, involving airfreight. • Policy implications – opportunity for stewardship / certification programs.	• Cooperatives report data on regular basis, but formalization process often stopped half way. • Tension with regard to role of cooperatives – material as donation vs. collection as a service. • Mobile phone tracking applications can improve coordination and documentation, but their design requires consideration of the existing practices in the cooperative.	• Two distinct design paradigms reflecting the goals of the system provider. City initiated systems emphasize actionability and service delivery, independent systems emphasize discourse and accountability. • Design factors have an effect on the discourse: on the tone, on the kind of arguments reporters make. • Regulatory effect of design decisions - opacity through transparency.

First essay: putting matter in place: monitoring waste transportation

The first essay presents a case study measuring the characteristics and environmental performance of waste transportation through a participatory sensing experiment.

Using self-reporting location sensors attached to individual items of waste and recyclable materials with the help of local volunteers, the experiment was designed to measure transportation distances, map the routes, and identify the network of facilities involved in waste disposal and recycling in Seattle. By observing the trajectories of individual items through the material streams of disposal, recycling, and take-back systems, the method used provides a systemic view from below not possible using existing data sources.

The collected data allows an estimation of the environmental impact of waste transportation by measuring the transportation distance with respect to material stream and means of transportation. The essay answers the following research questions: (1) to what extent can waste transportation diminish the benefits of recycling? (2) To what extent is the final fate of a discarded item predictable through its material and the location where it was discarded? The third research question asks: (3) what are the implications and limits of active location sensing for the governance of waste infrastructure? Through semi-structured interviews with professionals and activists involved in waste management, the section identifies the potential value of the sensing method for the different actors involved in the governance of waste systems: social accountability initiatives, law enforcement, waste management industry, municipal governments, and finally, the users.

In the first case study, the observed system is investigated from the outside – no internal information was available from the service providers, haulers, or recyclers, which would allow tracing the trajectories of the waste-streams. Since the sensing approach does not require the consent of the system provider, the method allows therefore users or watchdog organizations to monitor the infrastructure and collect evidence without having access to proprietary information. The case-study addresses the limitations and biases of the resulting data set, and illustrates how the value of the collected data can be increased by matching it with existing public data sources, including waste contracts published by the city, facility information from the environmental protection agency, and real-time databases of shipping routes.

The experiment was conducted using an participatory sensing approach (Burke et al. 2006), involving individual users of the service in the collection of the data. The volunteers included 96 individual households, who participated in the preparation of tracked materials according to a predefined study protocol.

The results of the analysis highlight the shortcomings of existing data sources for the evaluation of waste systems, and shows that previously unavailable information about waste transports leads to a systematic underestimation of the environmental impact of waste transport. By identifying individual cases, where transportation likely neutralizes the estimated benefits of recycling, the paper also highlights a problematic aspect of mail-back and take-back systems: the outsourcing of waste transport to the postal system, an infrastructure that is not optimized for transporting waste. The decentralized nature and overheads in packaging, handling lead to a larger environmental footprint compared to centralized waste hauling systems. Based on the identified advantages and limitations, the essay locates the largest benefit of the approach for social accountability campaigns, where the collection of evidence for individual cases is more important than quantifying the performance of the whole system.

Second essay: tacit arrangements – data reporting practices of recycling cooperatives in Brazil

While the first case study addresses a lack of available data in formal waste infrastructures, the second case study investigates the role of data in a waste system, that is largely self-organized – the recycling cooperatives of waste pickers in São Paulo and Recife. In the past twenty years, Brazil has developed a number of innovative policies for integrating the informal sector into the formal economy on the national and regional level. Most recently, the national government promulgated a comprehensive National Policy for Solid Waste (Política Nacional de Resíduos Sólidos – PNRS), recognizing the work of waste pickers and granting them a central role in the country's recycling system. The policy requires national institutions to work with recycling cooperatives and incentivizes companies and business associations to create partnerships with them. Furthermore, the law introduces Extended Producer Responsibility (EPR) policy, which requires the comprehensive monitoring and tracking of material streams in the system. While the national policy creates new opportunities for recycling cooperatives, it forces the originally informal organizations to professionalize, plan, and document their operations. Despite a successful history of formalization, most cooperatives still operate at the boundary between the formal and informal economy, from which they emerged.

The second essay addresses two research questions: (1) how do waste picker cooperatives and associations respond to data reporting requirements from local governments and companies? (2) How can available location-based technologies improve the data management and coordination of these recycling cooperatives and associations?

While in the first essay location based technologies serve as a tool for passive observation, in this case study they are used as a tool for active coordination and organization. The used method involves semi-structured interviews and Participatory Design, involving the recycling cooperatives in the design of technologies. The participatory design process has both a practical and reflective aspect: the designed technologies should ultimately help the cooperatives in their daily operations, while the design process was also a means to better understand the organization of the cooperative. Semi-structured interviews accompanying the design process allow insights in how cooperatives relate to data: their practices of data collection, the relevance of data for them, the city, and the companies they are working with. This places the focus of the essay on professional accountability – the responsibility of data exchange between provider, the city, and other companies.

The essay highlights a problematic aspect of EPR - the difficulties of documenting the sources of materials and the recycling processes. Despite their formal status, most of the cooperatives operate in a grey zone between formal and informal. We found that municipalities show less concern about data reported by cooperatives, while recycling companies are more stringently regulated. However, since cooperatives sell their material to companies who have to document its origin, the burden of (or rewards for) data collection extends to the cooperatives. The participatory design projects discussed in the essay reveal possibilities and limits of location-based technologies for managing self-organized recycling systems.

Third essay: Infrastructure Legibility – a comparative analysis of open311-based citizen feedback systems

The third essay investigates how digital feedback systems re-shape the interaction between citizens and the city, using data from open311-based citizen feedback systems as a case study.

In the past decade, most large US cities have implemented non-emergency incident reporting systems via telephone helplines, websites, and recently mobile applications. During that period, these systems have evolved from service hotlines to public accountability instruments, to data sources for urban maintenance and finally, tools for civic engagement. This essay investigates how different premises of infrastructure governance are enacted in the design of the interface and the postings of its users. By comparing different citizen-reporting systems with regard to their design features and how they affect the interaction between citizen and city, the essay starts from the premise that the different interests of the citizens and the city are negotiated through the design of these system's interfaces.

Using data generated by two systems operating in Boston, the city-operated *Citizens Connect* and the independent product *SeeClickFix*, the study answers the following questions:

(1) Which assumptions about the users are embedded in the decisions guiding the design of online 311 platforms, and how are these assumptions translated into design features?
(2) Why do users submit reports, and how do the system's design features correspond with these motivations? (3) By what mechanisms and design principles do existing systems facilitate and constrain the interaction between citizen and city, consequently shaping infrastructure governance?

In this study, the unit of analysis is a user-submitted report, a single interaction between a user and the system. The location of the investigation is therefore the boundary of the system – between citizens and the city, users and service providers. The method for analyzing the citizen reports is a content analysis using open coding based on Grounded Theory (Glaser and Strauss 1967). The identified features are consequently linked to the design features of these systems identified in a comparative analysis.

The findings show that that different interfaces are associated with different styles of user interactions. The design factors and mechanisms used to shape the interaction include the level of public visibility of the submitted reports, the degree to which users can customize their requests, the incident categories used to format the user's response, and finally the degree to which other participants are represented in the interaction between user and the city. Based on these differences, the essay distinguishes systems that are designed for service delivery (such as Citizens Connect) from systems that have a social accountability focus (such as SeeClickFix).

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Putting matter in place – monitoring waste transportation

Preface

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While text and data analysis presented in this essay are the sole product of the author, the author acknowledges the intellectual contributions from the project team members:
Data collection, cleaning & categorization - David Lee, Malima I Wolf, Avid Boustani, Jennifer Dunham, Angela Wang, Eugene Lee. Software development: David Lee. Conceptual contributions: Rex Britter, David Lee, Malima Wolf, Assaf Biderman, Avid Boustani, Santi Phithakkitnukoon, Carlo Ratti.

The essay is an extended version of the author's first-year PhD paper titled "Putting Matter in Place: Investigating Waste Distance" (2010). This single-author paper was also the basis for a jointly published article in Journal of the American Planning Association:

Offenhuber, Dietmar, David Lee, Malima I. Wolf, Santi Phithakkitnukoon, Assaf Biderman, and Carlo Ratti. 2012. "Putting Matter in Place: Measuring Tradeoffs in Waste Disposal and Recycling." *Journal of the American Planning Association* 78 (2): 173–196.

Since they are based on the same source, the JAPA article and this essay are closely related in terms of their data, analysis, arguments and conclusions.

Abstract

Although the local, interstate, and transboundary movement of waste is a complex topic that encompasses many environmental, social and economic dimensions, empirical data are scarce about the actual routes and distances involved in waste removal. The Trash | Track experiment collected a data set of waste trajectories by tracking individual waste items using active location sensors. This essay presents an analysis of the geographic and temporal structure of the collection and transportation of Municipal Solid Waste and Recycling, and discusses its environmental and policy implications. It estimates the extent to which transportation diminishes the benefits of recycling and investigates how predictable the final fate of a discarded object is depending on its material characteristics and the place where it was thrown away. The findings show that the impact of transportation is under-estimated especially in the

case of electronic and household hazardous waste, and that the collection mechanism assumes a crucial role in this respect. Based on the case study, the essay concludes with discussing potentials and limits of active location sensing for making waste systems more legible and accountable.

The path of least resistance

According to the anthropologist Mary Douglas "dirt is matter out of place (Douglas 1966, 37)." If this would be the case, then all problems of waste could be solved by moving it – from the place where it is generated to a place where it is considered less harmful or disturbing. Throughout the past centuries, this appears to have been the guiding principle of waste management. However, the distances that waste had to travel until it was "in place" have constantly grown, and simple disposal is no longer accepted as an adequate solution.

Until the late 1970s, every city and larger town operated its own landfill, hence removal distances were very short. As leakage and ground water contamination from the usually unlined dumps became a problem, the 1984 hazardous and solid waste amendments of the Resource Conservation and Recovery Act banned such facilities and mandated the use of *sanitary landfills*, physically isolated from their environment (*RCRA*, 1984). While this measure was an important milestone for environmental and public health, it also led to higher operating costs and tipping fees, reduced the number of landfills, which became larger and were sited further away from the cities (Porter 2002, 55).

As waste transportation distances grew, new environmental and sociopolitical issues emerged. The siting of large new waste facilities raised questions of environmental justice on a municipal, regional, and international level, as the trajectory of environmental liabilities turned out to follow the path of least resistance to the vicinity of underprivileged communities (Bullard 2000, 3; United Church of Christ 1987). Within the United States, interstate waste trade has been the cause of many disputes between cities, regions and states. According to estimates, around 10% of MSW is disposed of in a different state

(Repa 2005, 2). Concerns about the environmental costs of transportation grew with waste removal distances, addressing the emissions of pollutants, energy consumption and the risk of accidents involving hazardous substances during transportation. But increasing transportation distances also increases the mental distance between the consumers and their waste, therefore promoting more waste generation, as awareness of the complex externalities involved diminishes (Clapp, 2002). Acknowledging these negative consequences of long-distance waste transportation, the European Union's waste policy and the international treaty on the control of transboundary movements of hazardous wastes known as the Basel Convention are based on the proximity principle, postulating that waste should be disposed close to where it is generated (Kummer 1999; European Commission 1999).

The interdependence of economic, environmental and social factors can be illustrated through the history of New York's waste system. For decades, all of the city's waste went to Fresh Kills Landfill, opened in 1948 as a temporary facility on Staten Island, which quickly became the city's main garbage dump and the world's largest landfill (Porter 2002, 55). Leakage problems and stricter regulatory standards made it clear early on that the landfill had to be closed. As the landfill approached its capacity, tipping fees rose sharply to discourage the dumping of commercial waste, incentivizing haulers to ship the waste to more distant places. Consequently, many new transfer stations were built throughout the city to reload the garbage from the haulers' collection trucks onto larger vehicles – trucks, trains and barges. The new facilities caused social tensions and the rise of the environmental justice movement, as the transfer stations were located in poor neighborhoods in Brooklyn and the Bronx (McCrory 1998). With diminishing options for disposal and a lack of oversight and enforcement, waste followed increasingly erratic trajectories, exemplified by the famous example of trash barge "Mobro 4000," carrying Municipal Solid Waste from New York City to Belize and the Gulf of Mexico and back again, after it was initially rejected at a waste-to-energy facility in North Carolina (Kane, Kinsley, and Lamar Jr. 1987).

Research problem and questions

One of the central problems the waste management sector currently faces is a lack of information about its own operation, especially in the context of Municipal Solid Waste (MSW). The handbook of solid waste management lists seven major issues: increasing waste quantities (1), aggravated by the fact that a substantial amount of waste is not reported in the national MSW totals (2), which is partly due to a lack of clear, commonly shared definitions in solid waste management (3) and a lack of quality data (4). On the policy side, the roles of federal, state and local governments are not clear (5), resulting in a lack of even and predictable enforcement regulations and standards (6) and interstate and inter-country waste issues (7) (Kreith and Tchobanoglous 2002, 1.2).

What all of these issues have in common is that they are related to information: how it is collected, managed, exchanged and put into action. The MSW system is especially plagued by significant gaps in the available information – household hazardous waste and electronic waste in the form of consumer electronic devices and appliances are exempt from the treatment and reporting regulations applied to commercial and hazardous wastes. Uncertainty exists especially about the movement of MSW. Very little actual waste transport data exists, and the U.S. Environmental Protection Agency (EPA) usually does not report any transportation-related statistics in their annual MSW reports. In other words, precisely the part of the waste system that citizens are most exposed to, is in many ways the least transparent.

Yet, people do have questions about the way their waste services are managed. In the absence of stringent federal regulation and sufficient accountability mechanisms, the central question of this chapter is to what extent the gaps in the knowledge about our waste systems can be closed through citizen action, through bottom-up data collection and investigation.

Using participatory sensing of Seattle's waste system as a case study, this chapter seeks answers to three distinct research questions. The first question addresses a substantive gaps in the available data

– the distances and impact of waste transportation, which currently cannot be measured using existing data sources. In order to evaluate the environmental impact and the geographical aspects of waste removal, it is important to understand the relationship between the properties of the discarded objects and their end-of-life transportation distances, the collection mechanism and the geography where the items have been disposed. The first research question is therefore:

RQ1: To what extent can waste transportation diminish the benefits of recycling? To what extent does this distance depend on the material of the item and the location where it was discarded?

While transportation distance is only one of many factors, it is currently not measured and widely neglected in the assessment of waste systems. Combined with the information about the mode of transportation, the results will allow answering the question to what extent waste transportation - the energy used and greenhouse emissions generated - diminishes the positive effects of recycling. The second question is a question of compliance and accountability - based on their material composition; do things end up where they are supposed to go?

RQ2: To what extent is the final fate (i.e. whether the tracked item ends up in a landfill, recycling or special disposal facility) of a waste object predictable by its material and the location where it was discarded?

This question is especially relevant in the context of electronic and hazardous waste, a field poorly covered by available data sources. In many cases, it will not be possible for the sensors to capture the whole journey of a waste material, especially in the case of recycling chains. However, the facilities visited along the way can be expected to allow conclusions about the final fate of the object. The third research question addresses the policy implications of bottom-up data collection methodologies:

RQ3: What are the possibilities and limits of active location sensing for the governance of waste infrastructure?

Through a series of expert interviews, this question will explore implications for the governance of waste systems, its application areas of the waste tracking approach, and address the limitations and pitfalls of the method.

Economic and technical background, existing work

Transportation is a significant factor for the economics of waste systems. According to the city of Seattle, 16% of the Solid Waste Fund has been used in the year 2008 for waste collection and 29% for hauling and disposal (Seattle Public Utilities 2010a). Transportation is an important factor especially in the case of electronic and hazardous wastes, where less treatment facilities exist. Since these wastes are ubiquitous but appear in small quantities, curbside collection is not an option. The best mechanism for collecting household hazardous and electronic wastes is still subject to debate. Currently cities and collection companies evaluate waste stewardship programs that rely on the participation of the residents, including take back- and mail back programs through the retailers, collection at permanent facilities, municipal buildings or during temporary events (Michaelis 1995). As Table 1 shows, all of these mechanisms involve a substantial amount of transportation, no single strategy is clearly superior compared to the others (Norton-Arnold & Co., URS Corp., and Herrera, Inc. 2007; Office of Solid Waste 2008).

Table 2 Collection options for Electronic Waste. Source: Kang and Schoenung, (Kang and Schoenung 2005)

Summary of collection options and transportation responsibilities

Collection options	Responsible for transportation		Advantages	Disadvantages
	To collection site	To recycling site		
Curb side	–	Local government or recycler	Convenient. Resident participation	Potential theft and abandonment. Need extra sorting. High transportation cost
Special drop-off event	Consumer	Local government or recycler	Increase recycling awareness. Good for rural area	Irregular collection amount. Need storage space
Permanent drop-off	Consumer	Local government or recycler	High sorting rate. Low transportation cost. Most cost-effective	Need regular checking. Not effective for all communities
Take-back	–	OEMs or recycler contract with OEMs	No collection site needed	High shipment cost. Need special packaging. Consumers visit shipping location
Point-of-purchase	Consumer	Retailer	Low cost. High visibility if promoted by retailer	Retailer commitment. Need storage space

OEM: original equipment manufacturer.

Landfilling

From an economic standpoint, the optimal location for a landfill is determined by the cost of land and the cost of transportation. The cost of disposal, or the tipping fee at a landfill depends on parameters such as land value, construction and maintenance costs per volume of discarded waste, maximum capacity and negotiated compensations for adjacent communities (Jenkins, Maguire, and Morgan 2004). Most landfills have lower tipping fees for waste from local municipalities. Depending on these different factors, landfilling waste can be both the cheapest as well as the most expensive form of disposal. A review of disposal costs shows that landfilling has the greatest variance in cost, compared to incineration or composting (Table 3). 2010 data from Washington State (Table 4) shows a similar range, with tipping fees ranging from 22$ per ton to up to 102$/t in 2008/09 (Washington State Dep. of Ecology 2013).

Table 3 Waste Facility Operation and Maintenance Costs, 2002, reproduced from (Kreith and Tchobanoglous 2002)

Typical Operation and Maintenance Costs for Composting Facilities, Combustion Facilities, and Landfills

System	Major system components	Cost basis	Cost $*
Composting			
Low end system	Source separated yard waste feedstock only; cleared, level ground with equipment to turn windrows	$/ton	20-40
High end system	Feedstock derived from processing of commingled wastes; enclosed building with concrete floors, MRF processing equipment, and in-vessel composting; enclosed building for curing compost product	$/ton	30-50
Waste to Energy			
Mass burned, field erected	Integrated system of a receiving pit, furnace, boiler, energy recovery unit, and air discharge cleanup	$/ton	40-80
Mass burned, modular	Integrated system of a receiving pit, furnace, boiler, energy recovery unit, and air discharge cleanup	$/ton	40-80
RDF production	Production of fluff and densified refuse-derived fuel (RDF from processed MSW)	$/ton	20-40
Landfilling			
Comingled Waste	Disposal of commingled waste in a modern landfill with double liner and gas recovery system	$/ton	10-120
Monofill	Disposal of commingled waste in a modern landfill with double liner and gas recovery system, if required	$/ton	10-80

* All cost data have been adjusted to as Engineering News Record Construction Cost index of 6500

Table 4 Tipping Fees at Landfills in Washington, in $/ton, for the years 2008/09, source: WA Department of Ecology (Washington State Dep. of Ecology 2010)

Facility Name	County	2008/09
Asotin County MSW Landfill	Asotin	43.97
Cedar Hills Landfill	King	102.05
Cheyne Road Landfill	Yakima	23.20
Cowlitz - B	Cowlitz	37.30
Delano Landfill (planning to close 2009)	Grant	57.20
Greater Wenatchee Regional Landfill	Douglas	49.85
Horn Rapids Landfill	Benton	46.57
LRI Landfill (304th Street)	Pierce	101.95
Okanogan Central Landfill	Okanogan	74.00
Roosevelt Regional Landfill-MS	Klickitat	22.75
Stevens County Landfill	Stevens	51.00
Sudbury Road Landfill	Walla Walla	51.45
Terrace Heights Landfill	Yakima	23.20

Note: Tip fees were reported on the annual report for which waste numbers were for the previous calendar year. Tip fees were likely for the year in which the report was submitted.

Recovery and valorization of recyclable materials

For collecting recyclable materials, Seattle uses single stream curbside collection. From the nine million tons of Municipal Solid Waste generated in Seattle in 2009, about five million tons were reclaimed through recycling (Washington State Department of Ecology 2010). While separating recyclables at the source through the residents can increase the purity of the collected materials, single stream collection has the advantage of a cheaper and simpler collection by being able to collect multiple materials on a single trip without complex mechanical equipment. In Single-Stream Recycling, separation takes place in a Material Recovery Facility (MRF), where metals, different kinds of plastics and glass are separated through automatic and manual processes.

Unlike landfills, MRFs occupy less space and are often located in the industrial areas inside the city. The Allied Waste Recycling Center, a modern MRF is located just one mile south of downtown Seattle (Rabanco Inc.). However, for most materials this is only the first stop: according to the city of Seattle, between 70% and 100% of its paper and cardboard waste are exported to Asia (Seattle Public Utilities 2003).

The value of recyclable materials depends on a number of factors. Besides the intrinsic value of the involved materials, these factors include the purity and grade of the collected items, the degree to which they are sorted, and the density of compaction. Comingled recyclables including glass, metals and plastic usually have lower price than the value of individual materials contained in the bulk, making it profitable to extract materials such as aluminum, steel, or copper. Other materials have a negative intrinsic value, for example because of their toxicity, and have to be extracted to comply with environmental regulation. Finally, some materials such as glass have little intrinsic value, are inert and non-toxic. Those materials are extracted to minimize street litter or reduce overall waste volume.

Processing toxic waste

Within the scope of MSW, current legislation uses different degrees of toxicity. Moderate Risk Wastes (MRW) includes Household Hazardous Wastes (HHW) and covers toxic materials that occur in small volumes such as certain paints and cleaners, as well as glue. While most HHWs are potentially harmful, they can be legally disposed in certain circumstances in the regular garbage. In contrast, Universal Waste, a subset of Hazardous Waste, is generally banned from the trash. This class contains most batteries, electronic appliances, fluorescent light bulbs, and cathode-ray tubes. Regulations for the treatment of Household Hazardous Wastes differ from state to state. For example, while California bans the disposal of all batteries in regular trash (Waste Prevention Information Exchange 2009), Washington allows the disposal of alkaline batteries in the MSW stream. Other legislations and treaties, such as the Basel Convention and the European WEEE Directive, generally ban electronic waste from household trash (European Parliament, the Council and the Commission 2003).

Greenhouse gas emissions and energy consumption

Based on its chemical composition, 1 Liter diesel produces 2.68 kg of CO2 when burned in a combustion engine (U.S. Environmental Protection Agency 2006). Since a fully loaded 22 US ton Garbage Truck has an average fuel consumption of 6 miles/gallon[4] (Gaines, Vyas, and Anderson 2006), it emits about 0.048 kg of CO2 Equivalent per kilometer per US ton.[5] A garbage truck travelling 100 km to a landfill and back again would produce 210 kg of CO2 – not counting the emissions of individual car trips to collection points. In comparison, a two-person US household generates on average 362kg of CO2[6] and 17kg[7] of waste per week (U. S. EPA Office of Atmospheric Programs 2006) (Seattle Public Utilities 2010a).

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[4] or 2.55 km/l

[5] The EPA uses a lower value of 0.04kg CO2E/ton-mile in its WARM model (U.S. Environmental Protection Agency 2006)

[6] Converted from 41,500 lbs. / year specified by the EPA

From the energy perspective, one liter diesel corresponds to 36.4 MJ energy. Different modes of transportation require different amounts of energy to move the same mass (Table 5). It is worth noting that a tenfold amount of energy is necessary to operate a garbage truck compared to a train moving the same mass. Transfer stations and landfills with rail connection, such as Seattle's main MSW landfill in Cedar Hills), allow further improvement by addressing the 'last mile' problem of rail- and water-bound modes of transportation.

The EPA estimates an energy consumption of 560 MJ per ton of material landfilled, corresponding to a transportation distance of 230 km driven by a heavy truck using the values of Table 5. Counting both directions, this would result in an average landfill distance of 115 km.

Table 5 Fuel consumption for different modes of transportation (Davis, Diegel, and Boundy 2009)

Mode of Transport	BTU per short ton mile	kJ per ton kilometer
Class 1 Railroads	341	246
Domestic Waterborne	510	370
Heavy Trucks	3,357	2,426
Air freight (approx.)	9,600	6,900

The environmental impact of transportation

Distance is only one of many contributing parameters for evaluating the overall environmental impact of a product or a process. Existing literature suggests that transportation plays a minor role for the environmental impact of MSW and curbside recycling (Thorneloe et al. 2002). A comparative Life Cycle Assessment (LCA) by Morris found that the benefits or recycling in terms of energy conservation easily compensate for the losses generated by the collection and transportation, processing and re-manufacturing of household recyclable materials (Morris 2005). The EPA waste reduction model

[7] Converted from the value 2.7 lbs. per resident per day

(WARM), a LCA framework for MSW, uses a constant factor to account for transportation emissions during waste removal, which generally shows little effect on the overall result (U.S. Environmental Protection Agency 2006). However, the WARM model does not account for long distance waste transport using multiple modes and the authors acknowledge that this area deserves closer attention (Scharfenberg, Pederson, and Choate 2004).

The impact of waste distance seems especially relevant in the context of recycling electronic waste, which contributes 2% of the volume of the solid waste stream (Office of Solid Waste 2008). Transportation is often the most costly step in the e-waste recycling process (Lonn, Stuart, and Losada 2002), accounting for up to 80% of the total recycling costs (Kang and Schoenung 2005). However, waste transportation distances and therefore costs vary greatly depending on the collection mechanism used (Lonn, Stuart, and Losada 2002). Reusable, but heavy glass containers favor local reuse, but become less advantageous as transportation distances grow (Fairlie 1992).

Approaches to tracking waste

Waste tracking by traditional means is time-consuming and requires investigative skills. Watchdog organizations such as the Basel Action Network have conducted a number of reports following the trajectories of electronic and hazardous waste to informal recycling villages in Asia and Africa (J. Puckett et al. 2002; Jim Puckett et al. 2005).

Waste tracking can be accomplished through a collective of volunteers. To monitor oceanic currents, Ebbesmeyer and Ingraham followed the trajectories of 29,000 rubber toys that fell from a cargo ship into the North Pacific Ocean. From these easily identifiable toys, the small fraction of 400 were recovered and reported by volunteers, who found them on beaches in Alaska and other places (Ebbesmeyer et al. 2007).

Tracking garbage using active location-sensing technologies further simplifies the process, but is still is a challenging task: the physical conditions in the waste removal stream are hostile to the operation of electronic sensors, and the huge range of possible reasonable destinations and trajectories countless require a very large sample. The sensors cannot practically be recovered once they enter the waste stream. In 2004, Lee & Thomas have conceptualized the possibility of waste tracking using active GPS location sensors. The authors proposed using radio transmitters as a back-channel for the collected location information (Lee and Thomas 2004). Greenpeace has used this approach for an investigative report following the trajectory of two broken television sets from the UK to Nigeria (Greenpeace International 2008).

Supply chains are monitored mainly using passive tracking technologies such as Radio Frequency Identification (RFID). RFID tags are much cheaper than active location sensing, but they require a pervasive infrastructure for detection that is not yet present, since the tags can only be detected at a very short range. If broadly adopted by the waste management sector, RFID could be valuable for tracking the waste system (Binder et al. 2008).

Hypotheses

The null Hypothesis assumes that transportation distance cannot be predicted based on location and material of the discarded item:

> *H_0: The waste type of the discarded item and the geographic location of waste disposal have no significant influence on transportation distance and the facility type of its final destination.*

The two hypotheses investigated in this study are the following:

> *H_1: The reported waste transportation distance is depends on a) the waste category and b) on the geographic location of disposal.*

H_2: The end-of-life facility type of an item depends on a) the waste category and b) on the geographic location of disposal.

The municipality of Seattle uses a range of different collection and disposal mechanisms for different types material. Recyclable materials such as glass, metal, and paper are retrieved through comingled curbside collection and are subsequently sorted at a Material Recovery Facility. Electronic and HHW items including cell phones, Compact Fluorescent Light (CFL) bulbs or CRT monitors are not collected from the curbside (Seattle Public Utilities 2010b). CFLs can be mailed to recycling centers using pre paid envelopes provided by waste management. Computers and Monitors can be brought back to transfer stations or retailers who feed them into the recycling process. Municipal Solid Waste is brought to landfills and compost facilities. Based on the wide range of collection processes, it can be expected to find a large variance of transportation distances for different materials. As suggested by existing literature, it can be hypothesized that electronic devices have significantly longer traces than regular MSW, although little empirical information is available.

If the city's removal system works and the specified volumes diverted from the Municipal Solid Waste stream into recycling are correct, it should be expected that waste category has an impact on the fate of a discarded item. It is also plausible to assume that the expected fate of the discarded object diverges across different municipalities, since these have different access to facilities, different contracts with different companies.

Methods and data sources

Table 6 Used Public and Private Data Sources

Collected	
	Traces of household waste & recyclable items + metadata
Federal	
	EPA Facility Registry System data
State	
	Disposal data and tipping fees Facility I/O tonnages
Municipal	
	Solid Waste Collection Contracts Processing Contracts Long Haul Disposal Contracts Solid Waste & Recycling Reports
Private	
	RecycleNet Spotmarket Scrap prices 2010. Source: http://recycle.net/spotmarket

Table 6 lists the collected and the external data sources used in the experiment. The experimental data was collected in the metropolitan region of Seattle; the observed items were deployed in October 2009 and tracked until January 2010. During the deployment, over 2000 waste items provided by volunteers from Seattle and surrounding area were instrumented with active location sensors consisting of a GPS[8] receiver and a CDMA[9] transceiver as a backchannel. The volunteers participating in the deployment were recruited through an open call in the local media and via the project website. Every "trash donating" household was asked to prepare 15-20 different garbage items from a list of prioritized items prepared to ensure an appropriate range of different materials. From the pool of 105 volunteers that registered through the website, 90 households and six school classes were selected to participate. During the experiment, mobile teams of researchers visited these households, attached in collaboration

[8] Global Positioning System

[9] Code Division Multiple Access (CDMA) is a wireless transmission method used in many cell-phones

with the volunteers the sensors, and recorded additional information. After the sensors were attached, the volunteers were asked to dispose of the items in the way they would normally do.

While attaching the trackers, precautions had to be taken to protect the sensor from physical damage after entering the waste stream. The devices were encapsulated by a 1-2 inch thick layer of waterproof epoxy foam. Items smaller than the tracking devices were excluded in order to preserve the original appearance of discarded items. Organic waste was excluded from the experiment to prevent contamination. The environmental impact of 2000 tags was considered, but considered negligible in relation to the total volume of waste processed. However, a large-scale deployment would require a life-cycle assessment of the impacts introduced by the sensors, which has been evaluated for RFID tags in waste (Wäger et al. 2005).

Figure 4 Volunteer with donated objects and sensors before tagging. Photo: Christophe Chung, 2009

The acquired dataset consists of time-stamped, sequentially numbered location reports sent back by the device. To maximize the battery life of the sensors, the reporting intervals had to be maximized. To explore the best balance between accuracy and battery life, different groups of devices were configured to intervals of three, four, and six hours. During deployment, the researchers recorded additional information about the material properties and a photo of the discarded item, as well as the time and the street address.

By January of 2010, all the sensors had stopped reporting and the dataset was consolidated into a database. Before analysis, the collected dataset had to be cleaned from faulty reports; such as false location artifacts resulting from poor cellular network coverage on site. These location artifacts were relatively easy to detect, since they appeared in the dataset as identical geographical locations.

Items that failed to produce useful traces had to be excluded from the dataset. From the total number of 1971 deployed tags, 1915 have sent back at least 2 reports and 1279 reported traces that were longer than 250 meters; traces that did not cross this threshold, were excluded from the data set. These unusually short traces could result either from destruction of the sensor in the course of the collection process, or from a blocked transmission signal, for example by the body of the collection truck. In a second, manual clean up, traces were eliminated that obviously did not enter the waste removal system for other reasons, either because they have not left the volunteers home or the sensor has been removed manually – both cases could be identified by visually examining the reported traces. In general, the acquired traces can be expected being shorter than the actual trajectory of the item, since failure of the sensor can happen at any stage of the removal process. As a result, longest traces were not excluded as outliers, but rather as fortunate cases where the sensor lasted especially long.

Among the waste categories used in the experiment, glass, electronic waste and scrap paper had the lowest failure rates, reflecting the less hostile physical conditions encountered in the recycling stream. As expected, tags configured to six-hour intervals had the longest lifespan. After the clean up process, the dataset consisted of 1152 traces.

Other public and private data sources

It has been noted before that no existing data set allows the inference of a single waste item's trajectory. However, to interpret the data collected in the experiment, additional information is needed. First, it is crucial know whether the locations reported by the devices are associated with relevant facilities. The Environmental Protection Agency (EPA) maintains a database of all facilities and sites regulated under RCRA (U.S. Environmental Protection Agency 2009). The database includes information and locations of active or closed landfills, recycling facilities or all businesses that generate, process or ship hazardous waste. From the 2.5 million records of businesses monitored by the EPA, A subset of facilities involved with waste management, such as transfer stations, recycling centers and landfills was extracted. The resulting dataset of 13455 facility locations was compared to the locations reported by the location sensors, assuming a facility diameter of 400 meters to accommodate for landfill size. The output of this algorithm had to be manually refined[10] for each individual trace.[11]

[10] Special thanks to and Angela Wang, David Lee, and Malima I. Wolf

[11] This process required a manual inspection of each single trace, and was one of the most time consuming steps of the data preparation process, conducted by Angela Wang, David Lee, Malima I. Wolf, Eugene Lee and myself.

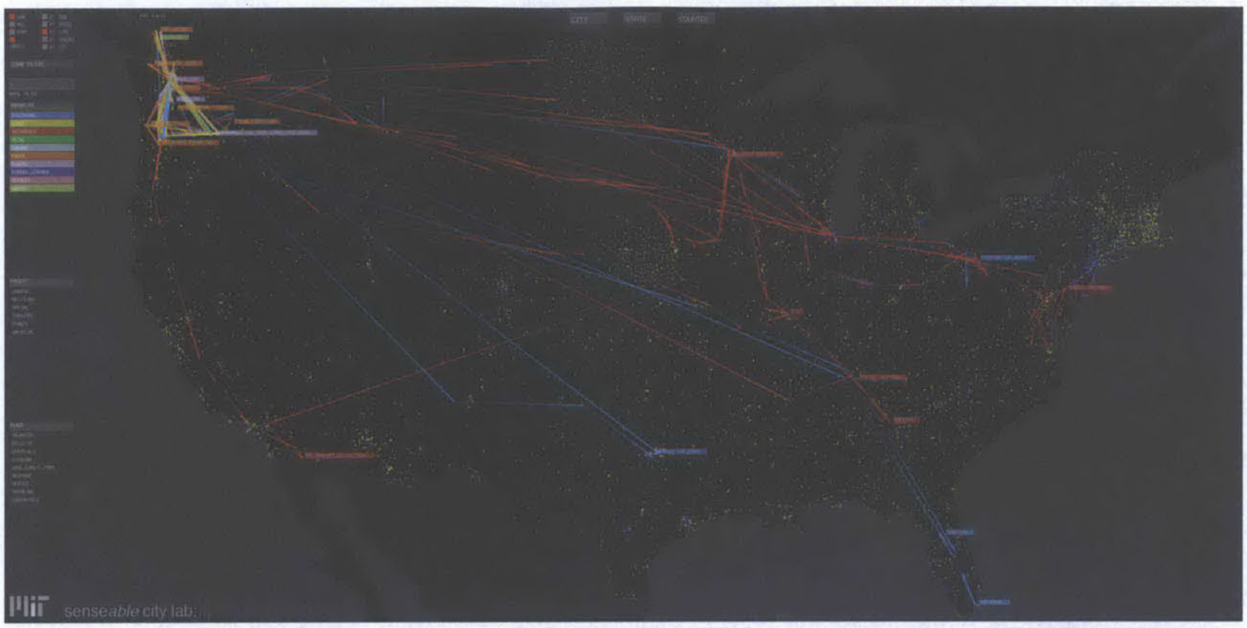

Figure 5 The collected traces overlaid with the locations of waste processing facilities from the EPA FRS database. Landfills are drawn in yellow, recycling facilities in blue. Visualization: Dietmar Offenhuber

The municipal contracts for the collection of garbage, recyclables and yard waste are published online (Seattle Public Utilities 2010c). To a limited extent, these contracts specify the logistics of the collection and removal process. Both city and Washington State keep statistics of the amounts of waste collected and processed by each facility, as well as landfill tipping fees (Washington State Department of Ecology 2010). Based on information from these sources, a basic topology of the waste removal chain can be inferred, including the volumes, facilities, and end destinations of different waste items. However, the contracts do not include information on the volumes of Household Hazardous Wastes and Electronic Wastes, which will receive special attention in this study.

Information about commodity prices for different kinds of scrap materials are available from municipal sources, but also private companies. First, the recycling contract with Rabanco Inc. specifies estimated values for different kinds of curbside recycling items. In addition to this data, real-time scrap market prices were acquired from a commercial database providing real-time commodity price and market trend information for different kinds of recyclable materials (RecycleNet Corporation 2010).

Methods

The collected data was analyzed using visual analysis on a trace-by-trace basis for identifying visited facilities, network analysis for inference of the structure of the removal chain, as well as a quantitative analysis for predicting distances an estimating the likelihood of end-of-life fate. Concerning the first question, the impact of waste type and location on waste transportation distance was estimated based on Ordinary Least Squares (OLS) model using categorical predictors. The regression testing the hypothesis is specified as:

$$Y = \beta_0 + \beta \mathbf{T} + \gamma \mathbf{P} + \delta I + \zeta R + \varepsilon$$

Where Y is the transportation distance, T a vector of 36 waste types coded as dummy variables, P a vector of eleven municipalities coded as dummy variables, ε represents the error term. Additional control variables are used to correct for technical aspects of the deployment, including the sensor's configured reporting interval in hours (I), and a dummy variable specifying the risk of tag removal (R). The unit of analysis is the trajectory of a single garbage item, constituted by the sequence of location reports - time-stamped geographical coordinates - received from the tracking device attached to the specific waste item.

The dependent variable is transportation distance, expressed in geographic or temporal terms. Geographical distance is calculated as the sum of the geodesic distances between the individual location reports in the sequence they were recorded. Since the sensors reported their locations in intervals of up to six hours, the approximated distance will be shorter than the actual distance the item traveled (if GPS location error is ignored). Temporal distance is recorded by the devices, and expressed as the duration in days starting from the item entering the waste stream and moving from the volunteers' home to the time of the last report sent by the device. Topological distance is expressed as the number of facilities visited during waste removal.

The independent variables are the waste type and category of the discarded item, coded as dummy variables. The sample is grouped into 36 types of waste that are based on the taxonomy used by the EPA. The 36 types are further grouped into 10 broader categories. The place of disposal is coded as the municipality where the item was disposed. Waste items were deployed in a total number of eleven cities in the greater metropolitan area of Seattle in order to allow for the comparison of waste removal service in different cities. A finer spatial resolution was not possible given the size of the sample.

The second question, the odds of an item ending up at a specific facility type will be answered using a multinomial logistic regression estimating the outcome for the items final destination, including landfill, recycling, special disposal and unknown. The independent variables are municipality where the item entered the waste stream. While it should be expected that the waste category has predictive power for the outcome, for example waste items have higher odds of ending up in a landfill than a recycling center, is included mainly as a variable controlling for the uneven distribution of waste objects across deployment locations. The specification for the second question is:

$$\text{logit}(p_i) = \beta_0 + \beta\mathbf{C} + \gamma\mathbf{P} + \varepsilon$$

Where **C** is a vector describing the broader waste category of the item, **P** is a vector describing the municipality where the item entered the waste stream, both vectors are coded as dummy variables. A list of variables used in the analysis can be found in Table 7.

Table 7 List of variables used

Variable Category	Name	Type	Description
Properties of the sensor			
	id	categorical	ID of the sensor
	tagrisk	binary	Risk of tag removal
	repNum	ordinal	Number of received reports
	repcycle	continous	Tag reporting cycle
	toxi	categorical	Toxine level
Material properties of tagged object			
	trashType	categorical	Type of Trash
	trashCategory	categorical	Broader Trash Category
	TrashName	categorical	Description of Item
	trashDisposal	categorical	Appropriate waste stream
	spotValue	continuous	Spot Market Value per ton
Deployment location			
	startPlace	categorical	Municipality of origin
	startZIP	categorical	Zipcode of origin
	startState	categorical	State of origin
Reported movement			
	durationDays	continuous	Reported duration by tag in days
	distanceKm	continuous	Reported distance by tag in km
	euclidDist	continuous	Euclidean distance by tag in km
	kmperday	continuous	Speed in km/day
	lndist	continuous	Natural log of distance
	endPlace	categorical	Municipality of destination
	endZIP	categorical	Zipcode of destination
	endState	categorical	State of destination
	endfacname	categorical	Name of the end facility
	endfac	categorical	Type of the end facility
	count	ordinal	Number of visited facilities

Analysis

A visual inspection of the mapped out traces reveals a number of basic patterns of the waste removal process (Figure 6). Most traces stay within a 300km radius around Seattle, with the landfills and composting facilities in Northeastern Oregon being a frequent destination (Figure 7). The location of the Allied Waste Recycling center in the south of Seattle emerges as a hub of the single stream recycling system. A small group of very long traces stands out visually; almost all of them associated with cell phones, printer cartridges, and rechargeable batteries. A few cell-phones even found their way to Florida, via Chicago and Atlanta. Two printer cartridges sent their last report from the Californian-

Mexican border. What is remarkable about these two cartridges that arrived at the same destination is that they were disposed in different parts of the city, but took very different routes – one by truck through California, the other by rail via Chicago, resulting in the longest recorded trace of over 6000km. While the tracking devices were for technical reasons not capable of sending reports from outside the United States, a number reports were received from seaports along Washington's and British Columbia's pacific coast as well as from the Mexican border region, which is still partly serviced by US cellular networks. Other items sent their last reports from coastal towns and harbor facilities along the route to the Pacific Ocean, indicating oversea export of paper, plastic and electronic waste.[12]

The visualized dataset also revealed some unusual events. Some traces led to residential neighborhoods after visiting the MRF – it can be speculated, that recycling workers salvaged objects from the material stream and brought them to their home. In another case, a gravel pit was the final reported location for a number of recyclable items that previously went through the MRF in Seattle, indicating an instance of illegal dumping.

Many objects sent their last report while they were still in transport, indicating a premature defect of the tracking device.

[12] Further examples of visualized traces can be found in the appendix.

Figure 6 Screenshot of the developed visualization system showing the cleaned dataset, blue traces represent Electronic Waste, red Household Hazardous Waste items. Visualization: Dietmar Offenhuber

Figure 7 Close-up on the Washington / Oregon area. The transfer-stations in Portland, OR and the landfill "Columbia Ridge" in northeast Oregon are clearly visible. Some items traveled across the Puget Sound to Vancouver, Canada. Visualization: Dietmar Offenhuber

Destination Facilities and the Topology of the Removal Chain

After each facility visited by the object has been identified, the routes can be examined in topological space (Table 8). Individual chains can be combined into a network of facilities and waste streams (Figure 8). The properties of this network, its central hubs and peripheral areas, indicate the hierarchy and interactions between different companies participating in the waste removal process. The inference of the facility network was complicated by the facts that many facilities service multiple waste streams, and that the EPA FRS database sometimes listed multiple facilities and companies at the same geographic location or in very close proximity. This introduced artifacts into the network, manifest in frequent 'bounces' between different facilities, which had to be manually resolved.

In the facility network, the individual material streams can be differentiated both by the place of origin (using ZIP code), as well as by material stream. Since the Seattle area is divided into different service districts managed by different companies, the facilities differ. Our traces have visited a maximum of four different waste facilities (excluding transportation facilities), with the Allied Waste Material Recovery Facility emerging as a central hub for the recyclable materials. Due to the low temporal resolution of the reported trace and possible premature device failure, it can be expected that not all visited facilities could be identified.

Table 8 Frequencies of visits to identified facilities

Destination Facility Types	Freq.	%
Landfill	110	9.6
Recycling facility	619	53.7
Special treatment facility	97	8.4
Transfer station	11	1.0
Transportation facility	150	13.0
Unknown destination	165	14.3
Total	1,152	100

Most visited Waste Facilities	Freq.	%
Cedar Hills Regional Landfill	34	28.1
Columbia Ridge LF	31	25.6
Finley Buttes Regional LF	20	16.5
Milton, WA Landfill	16	13.2
WM Transfer Station across from SRDS	9	7.4
Roosevelt Regional Landfill	5	4.1
304th Street Landfill (near Eatonville)	4	3.3
Bow Lake transfer station	1	0.8
Houghton Transfer Station and Recycling	1	0.8
Total	121	100

Most visited Recycling Facilities	Freq.	%
Allied Waste Recycling Center & Transfer S	424	68.5
North Recycling and Disposal Station	35	5.7
Cascade Recycling Center	33	5.3
South Recycling and Disposal Station	30	4.9
Shoreline recycling and transfer station	21	3.4
IMS Electronics Recycling Inc.	16	2.6
Seattle Iron & Metals Corporation	12	1.9
Smurfit-Stone Recycling Co	10	1.6
SP RECYCLING CORP TACOMA	9	1.5
Eastmont Transfer and Recycle Station	7	1.1
Seadrunar Recycling	5	0.8
SP Newsprint Depot	5	0.8
E-Cycle Environmental	3	0.5
Newberg Garbage & Recycling	2	0.3
Mercer Island Recycling Center	1	0.2
Pacific Disposal Recycling	1	0.2
Rabanco Eastside Disposal and Recycling	1	0.2
Savers Recycling Distribution Center	1	0.2
Wastech in Portland (plastics)	1	0.2
West Seattle Recycling Inc	1	0.2
WM Recycle America Kirkland	1	0.2
Total	619	100

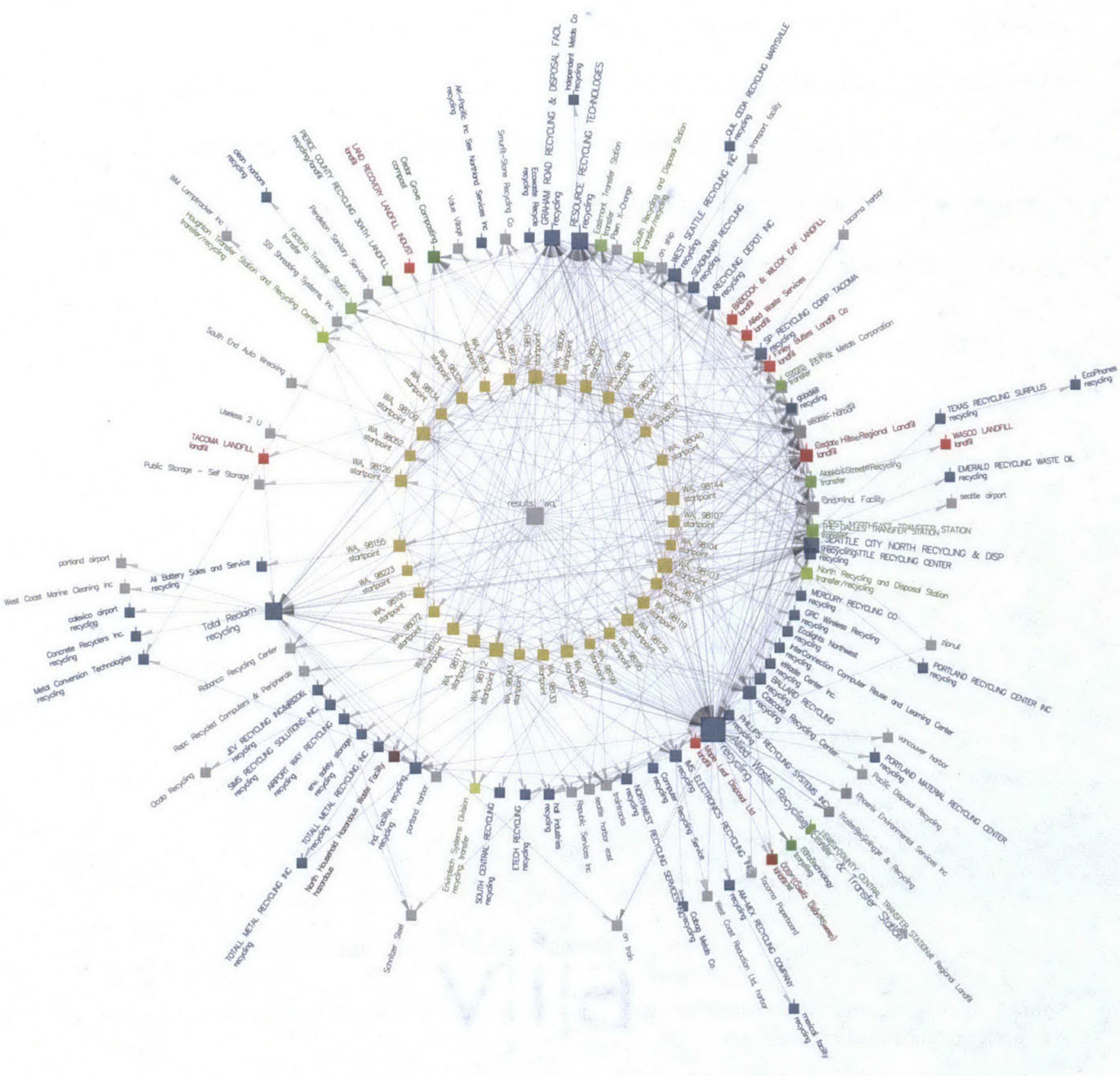

Figure 8 Representation of the facility network based on the sequence of facilities visited by the tracked items. Visualization: Dietmar Offenhuber

Descriptive Statistics

The set of the valid 1152 traces reported an average length of 114 km.[13] The longest trace, created by a printer cartridge, had a length of 6152 km. Comparing different waste categories revealed that Electronic and Household Hazardous Waste generally produced the longest, whereas glass and metal items reported the shortest traces (Figure 9). HHW and Electronic Waste reported also the longest traces in terms of temporal duration (Figure 10).[14]

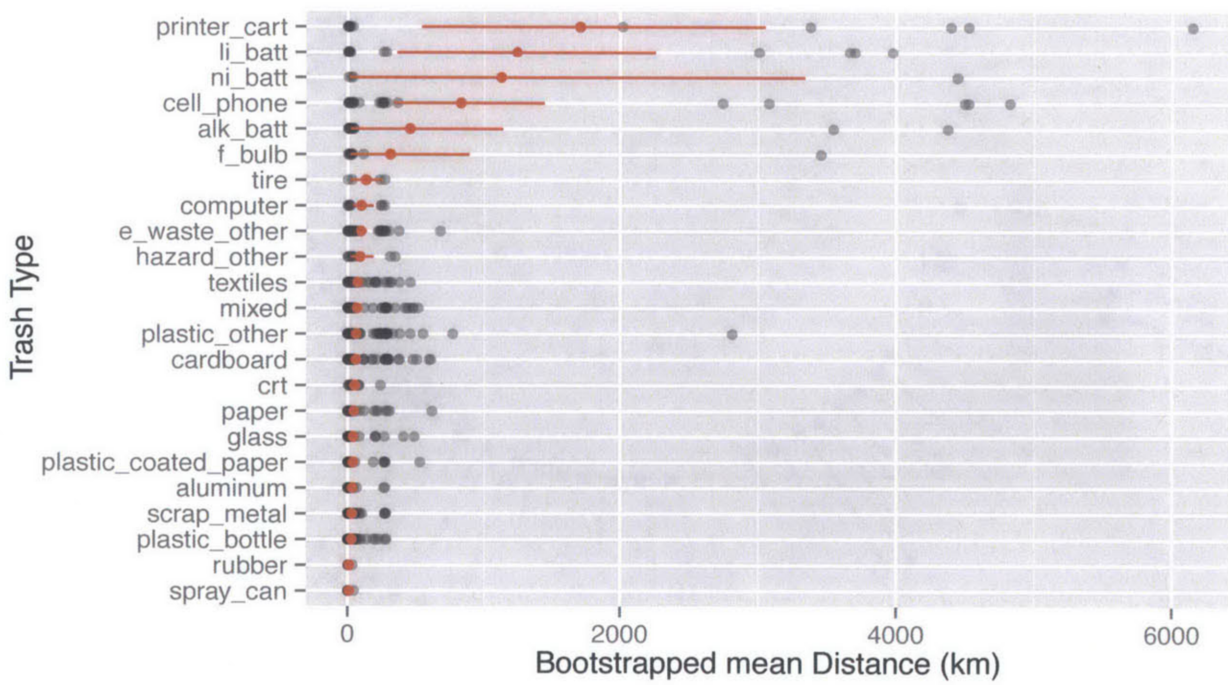

Figure 9 mean transportation distances by waste type with confidence intervals from bootstrapping (red) and scatterplot of individual observations.

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[13] median = 11.46km, SD = 508.3km.

[14] Refer to Table 12 for a distribution of valid traces by waste type.

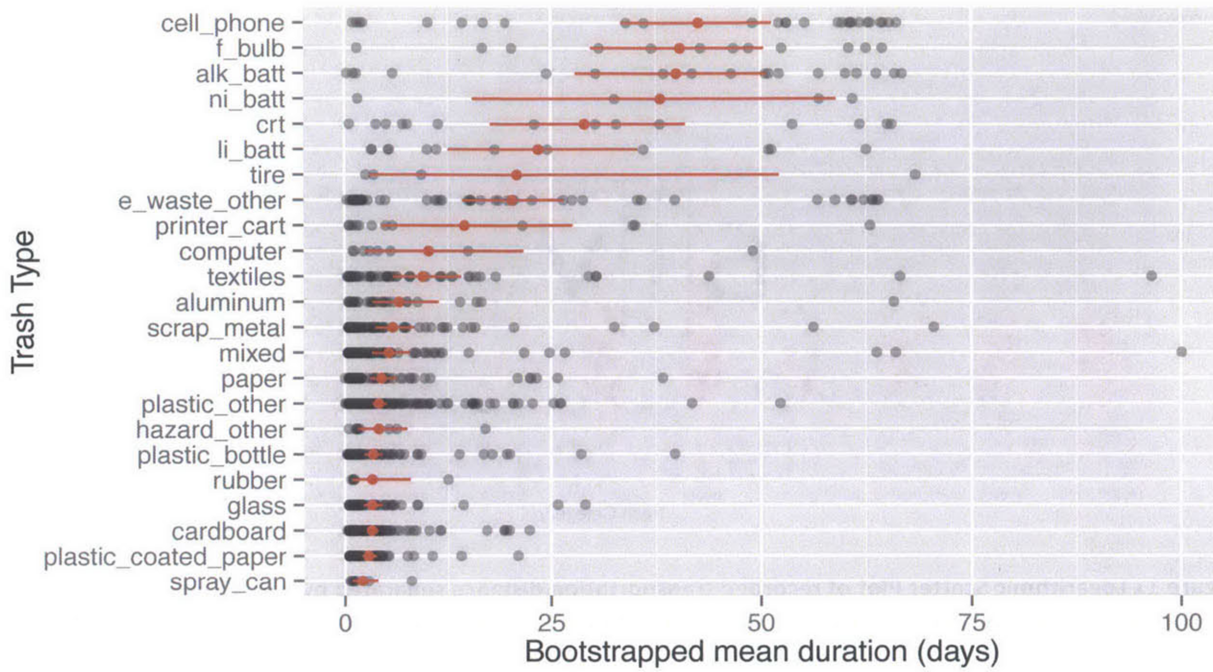

Figure 10 Mean durations with confidence intervals from bootstrapping (red) and scatterplot of individual waste item distances by waste type.

A logarithmic scatter-plot of each individual item's transportation distance (Figure 11) reveals three characteristic clusters: the majority of traces remain in a range between 10 and 50 km from their origin, with most of them sending their last report from recycling facilities in Seattle. A second, smaller cluster can be made out at a distance of approximately 300 km, corresponding to the distance to Seattle's main landfills in the Southeast. The third cluster finally combines 21 traces longer than 1500 km; all of them belonging to the electronic and hazardous waste categories.

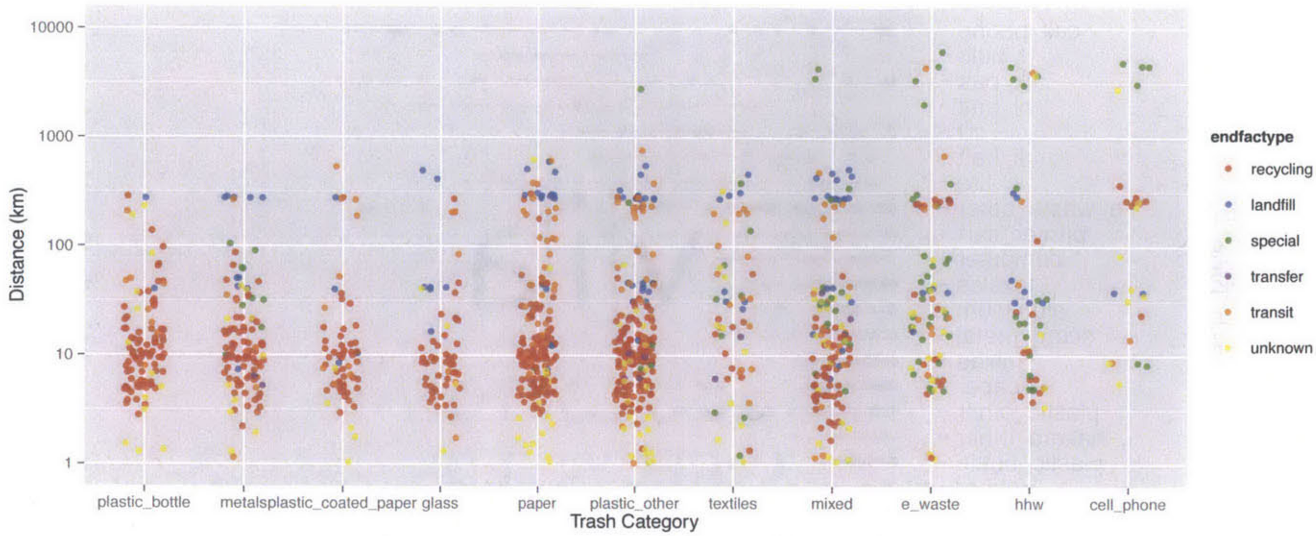

Figure 11 Logarithmic Scatter Plot of recorded transportation distance separated by waste category. On the vertical, logarithmic axis three distinct clusters associated with different waste streams become visible.

Facility Distances and the Commodity Value of Scrap Materials

Figure 12 suggests that items visiting transfer stations and recycling centers generally report shorter distances. This observation might be influenced by the fact that most sensors get destroyed while being processed the MRF, while the extracted materials continue their journey. Yet, it also reveals a spatial hierarchy in terms of facility distances: recycling centers and transfer stations are closer than 20 km from the respective points of collection, the average distance to a landfill is 183 kilometers, and special facilities such as electronics recycling sites are most distant with 650 km (Figure 12, left). This relationship is reflected in the monetary value of the recovered recyclables: the longest traces are associated with materials that either have very high or very low value (Figure 12, right).

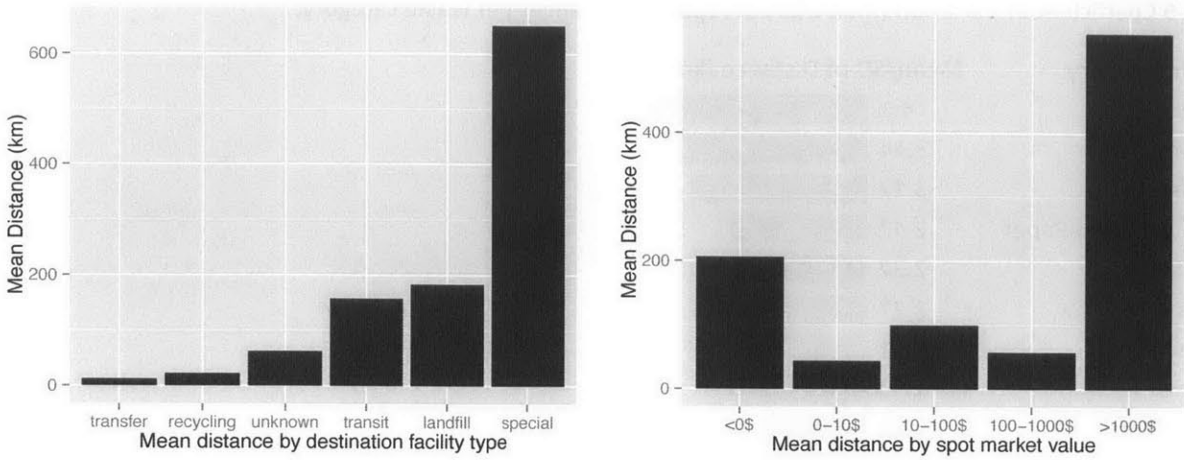

Figure 12 Left: Average facility distances from disposal location; right: distance by commodity value of scrap materials (source: spotindex.com)

To What Extent Do Transportation Distances Vary by Waste Type?

As shown in the results so far, electronic and household hazardous waste items reported the longest traces. But also the amount of variation in the reported distances between different items of the same waste type is an important parameter that can help to locate potential areas of improvement. Indeed, the results are somewhat surprising: the waste categories with the highest variance are non-recyclable wastes: the 'mixed waste' and 'mixed plastic' categories (Table 9). This is remarkable, since it reflects the structure of waste processing costs, which show the highest variation (mean/SD) for landfilling (Table 3).

Table 9 Coefficient of Variation (Mean/SD) of reported distances per waste category.

Trash Category	Mean/SD of Distance (km)
Mixed	4.1
Other plastics	3.44
E-waste	3.17
Plastic-Coated-Paper	2.42
HHW	2.37
Glass	2.27
Paper	2.1
Metals	1.93
Plastic bottles	1.88
Cell phone	1.87
Textiles	1.53
Total	4.46

RQ1 - Regression Analysis

Table 10 shows the results of a linear regression predicting transportation distance and temporal duration using the categorical predictors of material (models 1-3) and location of origin (models 2 and 3).

While transportation distance varies across all trash types and disposal locations, only six waste types reported differences in transportation distance at a statistically significant level ($p<0.05$). All of them are part of the electronic and hazardous waste category: alkaline, NiCad and lithium batteries, cell phones, printer cartridges and fluorescent light bulbs. Compared to the waste type, location seems to have less influence on transportation distance. In model 2, only a single location reports significantly shorter transport distances ($p<0.05$). The dummy variable controlling for the risk of tag removal is also significant for the transportation distance, indicating that the choice of the packaging strategy described earlier was important for the outcome. Overall, the two distance models explain about 25% of the overall variation in transportation distance ($R^2_{m1}=0.24$; $R^2_{m2}= 0.25$).

The third model uses the overall duration reported by the sensors as the dependent variable. The results are somewhat similar to model 1, but slightly nuanced: as previously, electronic waste and hazardous waste items report the highest significant coefficients ($p<0.001$). Besides batteries, cartridges, cell-phones and fluorescent light bulbs, the 10 significant waste types also include CRT Monitors, handheld electronic devices and other types of electronic waste. The only non-hazardous waste types that are statistically significant are textiles and tires.

In this model, location shows significant influence on the reported duration of waste removal. Two of the eleven municipalities, Mountlake Terrace and Lake Forest Park, reported significantly shorter values. The control variable for the sensor's reporting interval configuration is significant ($p<0.01$), indicating that battery failure was an issue: shorter reporting interval configurations led to overall shorter duration reported from the sensors. Overall, the model correctly predicts 42% of the temporal variation reported by the sensors ($R^2_{m3}= 0.42$).

The fourth model uses the speed waste movement, expressed in kilometers per day, as the dependent variable, in order to draw cues about the preferred mode of transportation. The estimation excluded sensors reporting for less than a day, since these would have distorted the velocity distribution. In the estimation, two waste types, Lithium batteries and Printer Cartridges, reported significantly higher velocities ($p < 0.001$). The average speed of Printer cartridge increased average reported velocity by about 116 km per day. Within that group, the fastest printer cartridge reported an average velocity of 683 km/day (from deployment to its final report). The latter value strongly suggests that airfreight played a role in the cartridges transportation; a cue that can be confirmed by inspecting the facilities visited by the trace (Figure 13).

Table 10 OLS regressions of transportation distance and duration using categorical predictors of waste type and location of origin. Guide for interpreting the results: the Constant value refers to the base categories: in the case of model 2, the material type "Plastic other" and location "Seattle." To evaluate the predicted distance for a different material or location, the numbers in the respective rows have to be added to the constant, i.e. 446.4 + 51.34 for Alkaline Batteries in model 1.

	m1		**m2**		**m3**		**m4**	
Dependent Variable	distance(km)		distance(km)		ration (days)		velocity (km/d)	
Constant	51.2	(63.79)	85.94	(66.49)	0.7	(1.68)	22.77 ***	(5.50)
Material (Ref=Plastic other)								
Alkaline battery	447.45 ***	(111.66)	445.21 ***	(111.79)	36.02 ***	(2.82)	-3.68	(9.24)
Aluminum	-43.95	(87.17)	-43.61	(87.42)	1.93	(2.21)	-4.43	(7.23)
Cardboard	-15.68	(48.74)	-23.98	(49.03)	-1.41	(1.24)	1.56	(4.05)
Cell phone	833.11 ***	(95.15)	839.89 ***	(95.46)	38.9 ***	(2.41)	7.21	(7.89)
Computer	19.44	(161.33)	18.38	(161.62)	5.31	(4.08)	-1.55	(13.37)
CRT	-36.78	(128.33)	-48.99	(130.29)	25.55 ***	(3.29)	-11.16	(10.78)
E-waste, other	43.71	(70.69)	43.78	(71.21)	17.07 ***	(1.80)	-9.18	(5.89)
Fluorescent bulb	315.26 *	(135.44)	299.31 *	(135.65)	36.06 ***	(3.43)	-12.47	(11.22)
Glass	-13.21	(63.01)	-15.28	(63.66)	-1.3	(1.61)	-0.68	(5.26)
Hazardous, other	47.53	(152.37)	40.94	(154.28)	1.3	(3.90)	0.57	(12.76)
Lithium battery	1235.65 ***	(134.32)	1240.92 ***	(134.92)	19.52 ***	(3.41)	36.81 **	(11.16)
Mixed	1.6	(51.27)	2.62	(51.51)	1.3	(1.30)	3.4	(4.26)
NiCd battery	1134.27 ***	(227.61)	1148.14 ***	(227.83)	35.58 ***	(5.75)	6.76	(18.84)
Paper	-8.22	(60.54)	-18.22	(61.25)	-0.12	(1.55)	1.55	(5.07)
Plastic bottle	-49.92	(52.83)	-47.98	(53.14)	-1.03	(1.34)	-5.75	(4.39)
Plastic-coated paper	-39.74	(63.68)	-42.87	(63.96)	-1.78	(1.62)	-3.3	(5.29)
Printer cartridge	1680.71 ***	(133.17)	1691.96 ***	(133.75)	10.66 **	(3.38)	85.28 ***	(11.06)
Rubber	-21.02	(202.89)	-37.06	(204.03)	-1.8	(5.15)	-13.26	(16.87)
Scrap metal	-35.71	(57.44)	-41.21	(58.13)	0.63	(1.47)	-3.96	(4.81)
Spray can	17.53	(163.55)	-1.15	(163.75)	-1.54	(4.14)	-10.12	(13.54)
Textiles	-6.6	(65.34)	-7.07	(65.49)	4.64 **	(1.65)	-3.23	(5.42)
Tire	46.83	(226.43)	32.73	(226.58)	14.96 **	(5.72)	15.05	(18.74)
Start place (Ref=Seattle)								
Arlington			10.83	(131.59)	2.46	(3.32)	4.19	(10.88)
Eatonville			-1	(105.60)	1.8	(2.67)	-0.43	(8.73)
Graham-Thrift			14.08	(263.76)	2.8	(6.66)	-4.16	(21.81)
Issaquah			-135.28	(76.06)	-1.25	(1.92)	-3.97	(6.29)
Lake Forest Park			-128.47 *	(62.74)	-5.14 **	(1.58)	-6.24	(5.19)
Mercer Island			-209.95	(137.24)	-3.7	(3.47)	-11.45	(11.35)
Mountlake Terrace			-52.38	(113.20)	-7.28 *	(2.86)	-4.78	(9.36)
Newcastle			-52.12	(146.27)	3.64	(3.69)	-10.84	(12.10)
Redmond			-91.61	(117.93)	-3.66	(2.98)	-2.88	(9.75)
Woodinville			-52.35	(131.69)	-4.06	(3.33)	0.33	(10.89)
Controls								
Reporting cycle	6.28	(11.47)	2.84	(11.94)	0.88 **	(0.30)	-1.14	(0.99)
Risk of tag removal	-85.26 *	(36.67)	-86.26 *	(36.77)	-0.92	(0.93)	2.99	(3.04)
attention	39.18	(225.86)	68.15	(229.10)	7.22	(5.79)	8.42	(18.95)
R^2	**0.24**		**0.25**		**0.42**		**0.1**	
N	**1147**		**1147**		**1147**		**1146.0**	

Standard errors in parentheses, * p<0.05, ** p<0.01, *** p<0.001

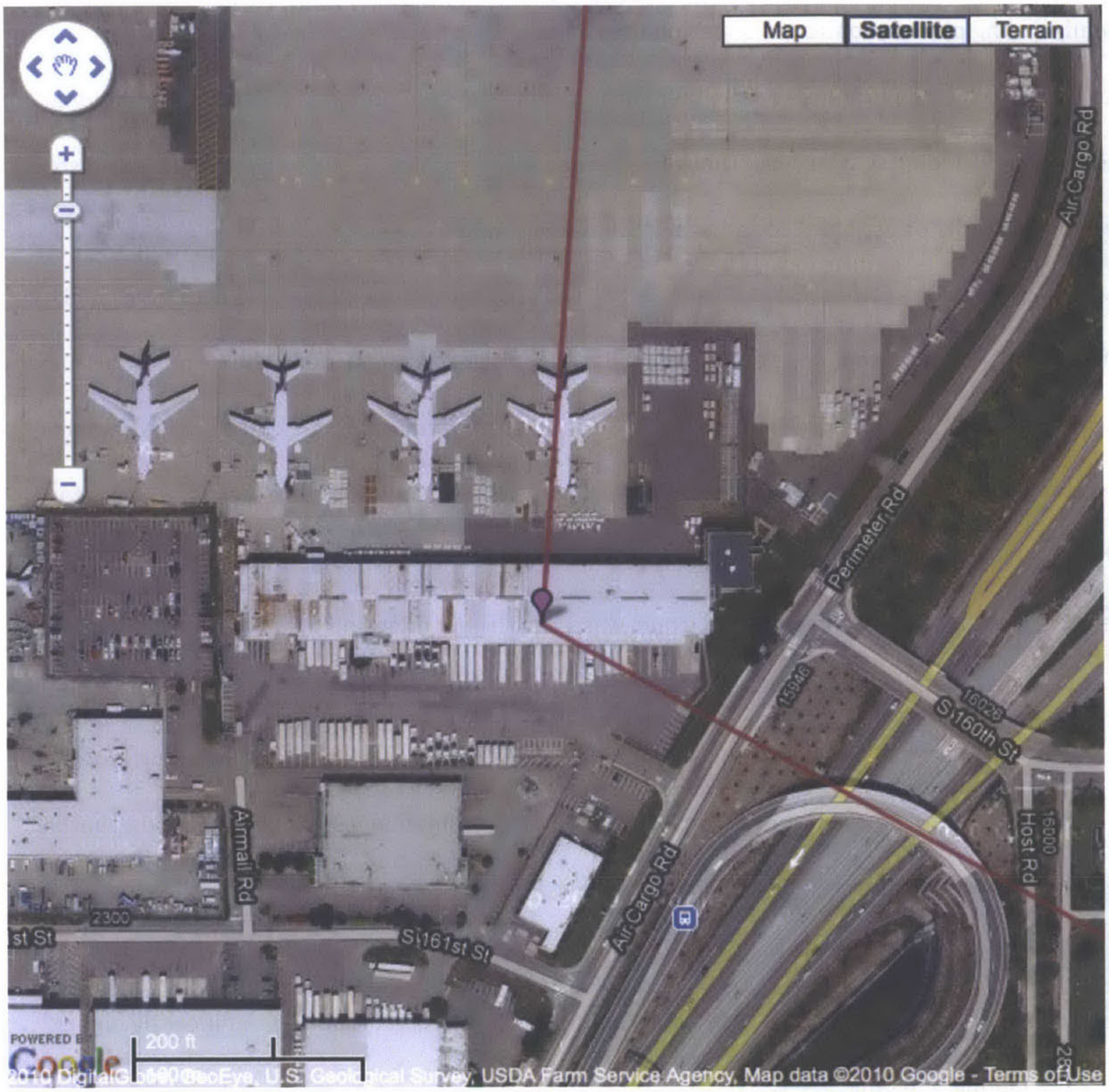

Figure 13 A printer Cartridge at the Seattle-Tacoma International Airport. Web-application: David Lee. US Geological Survey, USDA Farm Service Agency, reproduced under Google map fair-use policy

RQ2 – Multinomial Logistic regression

For answering the second research question, a Multinomial Logistic regression was used to predict the odds of an item ending up in a specific type of facility. Possible outcomes include landfills or other facilities related to landfilling waste, recycling centers and MRFs, special treatment facilities such as a remanufacturing plant for batteries or cell phones, or unknown destinations resulting for example from a final report sent while in transit or all other cases in which an item does not end up in a traditional waste stream (including scavenging). The waste category and municipality where the item was disposed were used as predictor variables coded as a set of dummy variables.

As could be expected from the exploratory analysis (Table 8), certain waste categories had significantly higher odds ending up at a recycling facility rather than at a landfill. These materials include glass, metals, paper, and plastic items, confirming that materials collected through curbside recycling are treated differently compared to waste. Interestingly, household hazardous have higher odds for ending up either at a special facility or at a landfill compared to the recycling facility outcome; however, these coefficients are not significant. Electronic waste had higher odds ending up at a special facility than either a recycling facility or a landfill, although also not on a statistically significant level.

Perhaps more striking is that the location of disposal reports significant influence on whether an item ends up at a recycling center or a landfill. Based on the estimation, especially rural and suburban areas that are more distant from Seattle have higher odds of disposed items ending up at a landfill rather than a recycling center or special facility. Specifically, the surrounding municipalities of Woodinville, Eatonville, Lake Forrest Park, Mercer Island, and Issaquah reported significantly higher odds of the landfill outcome.

Table 11 Regression Results for Question 2. Note: an odds ratio > 1 indicates an increased probability for the specified outcome compared to the base outcome (recycling), an odds ratio < 1 a lower likelihood of the respective outcome. For example, an odds ratio of 1.2 in the landfill column translates to a 20% higher probability of the specified waste type to end up at a landfill compared to recycling. The actual probability of the specific outcome can be calculated using the formula at the bottom of the table.

Relative Odds Ratios* for specified Destination Facility compared to Recycling as a Base Outcome

Landfill	Odds R.	z	Special Facility	Odds R.	z	Unknown Dest.	Odds R.	z
E waste	0.42	-1.24	E waste	1.99	-1.27	E waste	0.51	-1.45
Glass	0.26 *	-2.10	Glass	0.00	-0.01	Glass	0.09 ***	-4.99
Cell phone	0.41	-0.94	Cell phone	0.97	-0.05	Cell phone	0.46	-1.34
HHW	1.25	-0.32	HHW	1.90	-1.08	HHW	0.33 *	-1.97
Metals	0.23 *	-2.44	Metals	0.14 ***	-3.39	Metals	0.10 ***	-5.42
Mixed	0.76	-0.50	Mixed	0.42	-1.62	Mixed	0.38 *	-2.40
Paper	0.23 **	-2.65	Paper	0.03 ***	-4.87	Paper	0.14 ***	-5.07
Plastic bottle	0.03 ***	-3.96	Plastic bottle	0.00	-0.02	Plastic bottle	0.09 ***	-5.72
Plastic coated p.	0.15 **	-2.62	Plastic coated p.	0.00	-0.01	Plastic coated p.	0.11 ***	-4.69
Plastic other	0.26 *	-2.49	Plastic other	0.04 ***	-4.83	Plastic other	0.16 ***	-4.74
Arlington	0.00	-0.01	Arlington	0.00	-0.01	Arlington	0.58	-0.70
Eatonville	8.88 **	-2.92	Eatonville	5.06	-1.35	Eatonville	5.66 **	-2.83
Graham Thrift	0.00	0.00	Graham Thrift	3.42	-0.72	Graham Thrift	1.39	-0.22
Issaquah	4.03 **	-2.83	Issaquah	1.60	-0.65	Issaquah	1.57	-1.09
Lake Forest Park	2.83 **	-2.62	Lake Forest Park	0.75	-0.42	Lake Forest Park	0.98	-0.07
Mercer Island	5.45 *	-2.29	Mercer Island	0.88	-0.10	Mercer Island	0.34	-0.96
Mountlake Terr.	0.00	-0.01	Mountlake Terr.	1.05	-0.07	Mountlake Terr.	0.11 *	-2.06
Newcastle	2.78	-1.17	Newcastle	3.10	-1.25	Newcastle	0.44	-0.73
Redmond	0.00	-0.01	Redmond	0.00	-0.01	Redmond	1.40	-0.60
Woodinville	18.05 ***	-3.70	Woodinville	0.00	0.00	Woodinville	1.65	-0.58
Constant	0.49	-1.46	Constant	0.80	-0.49	Constant	2.88 **	-3.01
Observations	1152							
AIC*	2356.4							

$$\text{* Odds Ratio} = \frac{p_2 / (1 - p_2)}{p_1 / (1 - p_1)}$$

*Akaike Information Criterion

The environmental impact of transportation

Table 14 shows the recorded waste distances and the corresponding Green House Gas Emissions, assuming a typical 22-ton garbage truck with a fuel efficiency of 6 miles per gallon.[15] The distances involved in curbside recycling of glass, plastic and metal, the greenhouse gas emissions generated through the transportation impact seems in fact rather insignificant, compared to the emission factors used by the EPA WARM model for different waste types and treatment processes (Table 14).

[15] Value taken from (Gaines, Vyas, and Anderson 2006)

Glass recycling can be a borderline case. According to EPA WARM, the recycling of glass items gives the lowest GHG reduction among the materials collected at curbside. The traces collected from tracked glass items have a maximum length of 488 km (Table 14). This distance would translate to 0.023 tons GHG generated per ton of material (not counting the way back from the facility), which is substantial compared to the 0.076 tons of GHG saved in its recycling process.

For the long traces of household hazardous waste and printer cartridges, the emissions generated during the transport become significant. The longest trace associated with a printer cartridge generates 0.3 – 0.8 metric tons of greenhouse gases, depending on the mode of transportation and assuming that the vehicle is loaded to capacity. This is a substantial portion, that could neutralize the expected benefit of recycling: according to WARM, the recycling of 1 ton scrap computers yields a recycling benefit in terms of greenhouse gas reduction of 0.618 metric tons. While this is only a rough estimate based on the values provided by the EPA, it shows that long transportation distances involving multiple modes of transportation can in fact neutralize the recycling benefits. It goes without saying that beyond transportation, many other factors including toxicity are important for sensible end-of-life treatment choices. However, as multiple modes of transportation at very long distances are not covered in EPA's WARM model, these cases deserve special attention when evaluating product stewardship models and e-waste recycling at specialized facilities.

Advantages and limitations of bottom-up sensing

To what extent was the Trash Track project successful in produce evidence of misconduct? The recorded traces produced indications of unlawful dumping of waste in a gravel quarry that is not licensed for receiving waste. The fourteen objects received by this particular facility over the course of two weeks previously visited the Seattle's Material Recovery Facility, where they were either extracted as unrecyclable solid waste, or sent as recyclables for further treatment (Figure 14). Upon inquiry, the operator of the landfill denied ever receiving waste to his facility.[16]

The project therefore validated its potential as a social accountability tool for monitoring waste management practices from the outside and from the bottom-up. Based on the number of items reporting from the facility, and based on the timeframe, a case of illegal dumping is very likely.

However, the recorded data does not provide enough context to constitute evidence of illegal dumping. Many unobserved factors could have intervened: It is not clear whether the material left the Material Recovery Facility as recyclable material or as residual waste. Furthermore, it is not clear whether the objects came with a truckload of waste or became stuck in a truck that later carried construction waste, which the facility was permitted to accept. Nevertheless, such a finding could be a starting point for further inquiry.

Would it have been possible to answer the first two research questions using existing data? The published contracts with waste management contractors describe the general architecture of Seattle's waste system and loosely specify intended destinations, such as Cedar Grove Composting Plant. In many cases the contracts remained unspecific (i.e. just listing 'Asia' as a destination). Municipal and statewide Solid Waste and Recycling reports specify tonnages processed at individual landfills, transfer stations, and MRFs. For some facilities, also the mode of transportation is known, however, they account for only a small fraction of the whole system. Furthermore, the location and permits of facilities transporting, processing, and disposing waste are monitored by the EPA. However, a review of the database by the

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[16] The reply from the facility manager after inquiry about waste items received at the facility: "I have no idea what you are referring to. Our gravel facility located at (redacted) does not accept paper, aluminum cans, plastics or e-wastes. I do not know of a landfill that was located near our facility. No garbages or waste dumping were accepted at any time at our facility. We are permitted to accept concrete, asphalt, clean fill, topsoil, sod, stumps and brush." Source: personal e-mail conversation, July 2010

author reveals factual errors[17] and a categorization of facilities that is not always consistent across the country. Most importantly, the fate and trajectories of electronic and household hazardous waste is largely undocumented. Although recycling facilities processing e-waste report to EPA's Toxic Release Inventory program (TRI),[18] the origins of the processed materials are not recorded.

In conclusion, data about waste transportation does seldom exist beyond the first stop – in most cases, the transfer station or the MRF. Without such information, the environmental impact of waste transportation can only be estimated and not measured.

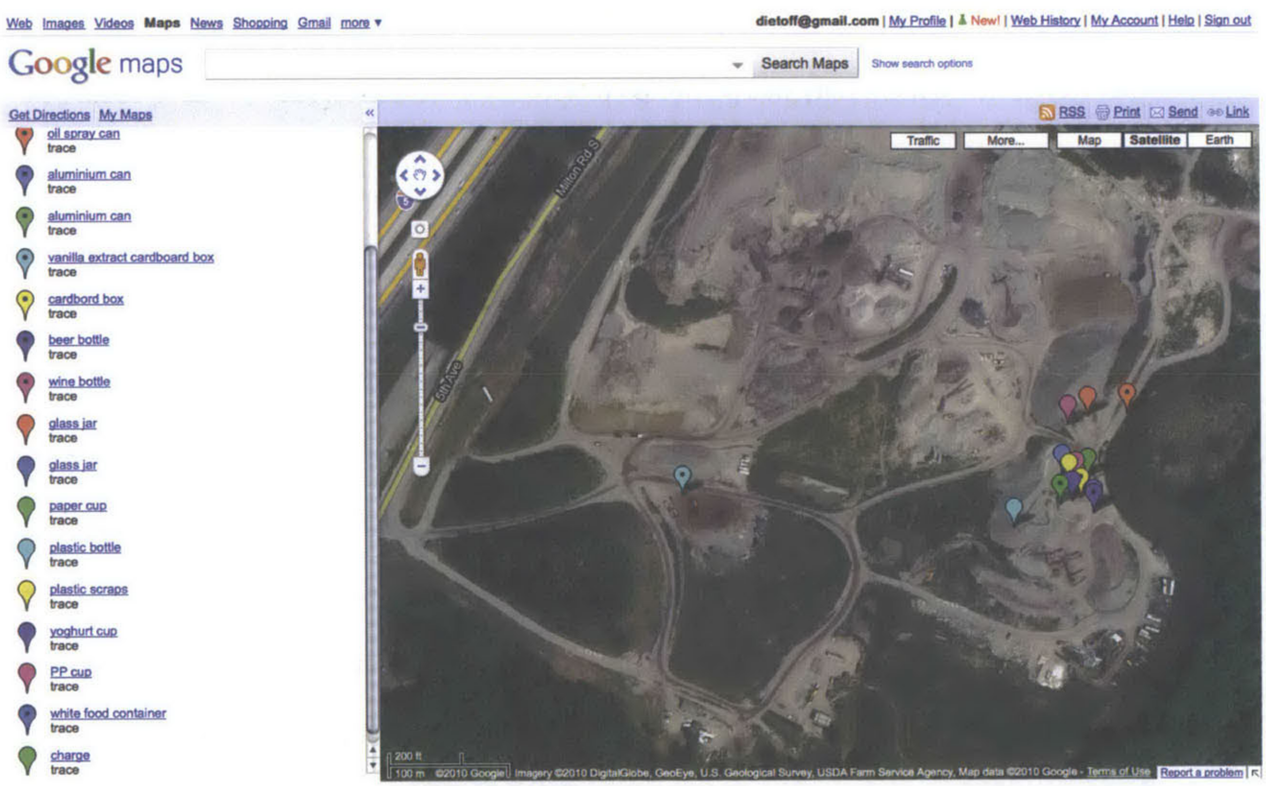

Figure 14 Google maps Screenshot with location reports from waste items at a gravel facility, which is not permitted to accept any kind of waste except construction waste. Web-application: David Lee

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[17] For example, Seattle largest MRF operated by Rabanco, Inc. is not classified as a Material Recovery Facility

[18] http://www2.epa.gov/toxics-release-inventory-tri-program

Limitations of the findings

But even with active location sensing, the possibilities for a complete quantitative analysis of waste trajectories are limited. The sample size used in our experiment was too small for a general assessment of the performance of a complete waste system. Due to the cost of a sensor and the corresponding data service plan, it is unrealistic to overcome this limitation within reasonable budgets. However, since the reported trace provides evidence of an actual process, even anecdotal findings can offer important insights. As illustrated in the case of suspected illegal dumping, also the outliers provide the meaningful information and should not be discarded. While the experiment was exploratory and covered a wide range of variables, a successful sensing effort has to narrow down on a specific pathway or collection mechanism.

Second, technical limitations are connected to the design of the experiment, but apply to some extent also to other participatory sensing projects using location-based technologies. The waste stream is a hostile environment for sensitive electronics, and the sensors can be expected to break at some point during their journey or run out of battery. The length of the reported trace therefore rarely represents the whole journey of the item. As a result, also average or median values are problematic. Furthermore, the cellular network necessary for reporting back is not always available, either because the signal is physically blocked by other material around the item, or the item is in an area with little or none cell-phone reception. Unfortunately, this is often the case for remote landfills and generally the case for large waterways and the ocean, including most international shipping routes.

A third problem is the generally non-probabilistic nature of data collected by volunteers, especially the presence of selection bias. It can be expected that the participants have a higher than average interest in environmental issues, therefore their recycling rate might be higher than average. Compliance is a second issue, some of the recorded data suggested that volunteers reclaimed the sensors instead of disposing them as intended.

These limitations can be addressed on three levels. On the technical level, the collected sensor data itself provides clues to discover flaws in the dataset. The task protocol for volunteers can be designed in a way to make it easier to discover false or fabricated information. Finally, the research design should acknowledge the intrinsic deficiencies and choose robust methods of analysis that do not depend on a perfectly random sample.

Policy implications of waste tracking

This section explores the role of waste tracking within the data ecology of the waste system, consisting of the governmental data sources, Data Sources from private companies, and data generated by citizens. In what way is the data collected in the Trash Track experiment relevant for governance of waste systems? Which purposes and groups can it serve? Following section explores scenarios, in which active location sensing can play a role. Scenarios are based on a series of interviews with experts from NGOs, industry, and government, who are involved in monitoring of waste systems (Table 16).

Tracking as a social accountability tool

Perhaps the most contended topic is the issue of international trade of hazardous waste and defunct electronic equipment. Paradoxically, recycling legislation aggravates the problem of illegal dumping and hazardous waste exports, since it creates loopholes in stringent environmental regulation. "Recycling is the password for shipping things to other countries," as Jim Puckett from the Basel Action Network (BAN) explains.

In the domain of waste exports, the lack of data is most severe. The Harmonized Tariff System Codes (HTS)[19] used to identify goods in foreign trade, does not capture waste exports, since the system does not distinguish between waste and non-waste. Export flows are measured in monetary value rather than volume and material. Finally, the lack of data is also stemming from the fact that the US did

[19] http://hts.usitc.gov/

not ratify the Basel Convention, making the export of hazardous waste legal. Because of this lack of data, waste exports from the US cannot be reliably estimated.

NGOs who advocate against waste exports are facing a problem to collect evidence of these practices. Conducting anonymous surveys among recyclers is less than promising, since it is unlikely that waste exporters will admit to a practice that is universally seen as harmful. Watchdog organizations therefore rely on investigative reporting, collecting anecdotal evidence for the practices and impacts of hazardous waste export. In the case of BAN, this means following the trajectory of shipment containers to Asia or Africa, documenting the environment in which the exported waste is processed, and collecting evidence for the origin of the waste: photos of asset tags, equipment plugs and so forth. Since this kind of investigation is highly time-consuming and difficult to scale up, the Trash Track approach offers a powerful alternative.

Any data collection with active location sensors requires linking the collected traces to additional data sources such as shipping information. Tracking containers is a simple task, if shipping numbers are known. The PIERS database contains all bills of lading in anonymized form, making it possible to track containers 5-6 months back.[20] Since all shipping operations use outdoor loading docks, it is possible to collect container numbers on the facility location.

Since national law does not provide many options for citizen lawsuits against exporters of hazardous wastes, even if they are illegal in the receiving country, BAN has to rely on the "court of public opinion" instead. For this purpose, anecdotal information is highly actionable, especially when quantitative data is not available. The documented cases present evidence of significant environmental and social harm; so the reconstructing the origin and chain of events in the particular case is more valuable than quantifying the larger effect, when it comes to bring policy makers to act. One such example of investigative reporting CBS 60minutes documentary on Chinese e-waste recycling villages led

[20] http://www.piers.com/

to the investigation and conviction of an American electronic recycling company (CBS News 2008; Parker 2013).

Tracking in law enforcement

The investigations of watchdog groups and citizen initiatives have limits. Under the community right to know provisions, citizens groups can make use of the public data generated by EPA, and use this data for crosschecking their own observations. In most cases, however, their data cannot be used in court, since the enforcer has to be the government, and enforcement agencies have to rely on their own data. Data from citizens typically serves as a starting point to launch an investigation, may be used as background information or serve as a blueprint for repeating the data collection.

Yet, also the enforcers of international environmental crimes such as the EPA or Interpol are heavily constrained. The first issue is a lack of resources. US Waste regulation relies mainly on self-reporting, which inescapably involves some level of fraud. Due to a lack of resources, the EPA cannot investigate such cases at a significant scale beyond creating symbolic deterrents. A second issue is an inherent conflict in the objectives of the law, which on the one hand wants to encourage recycling, but at the same time realizes that recycling makes violations less enforceable; for example by companies mislabeling illicit disposal as temporary storage for later recycling. A third issue constraining enforcement is the definition of waste in current policy: currently it has to be proven that a material is in fact hazardous waste under RCRA. In court, this means for example disproving defense arguments such as: "the CRTs looked fine when we put them in the container." WEEE legislature of the European Union is more comprehensive and includes explicit definition of waste.

Location tracking is a familiar method in law enforcement. The data collected are both evidence and indication for further investigation. Beyond the collected evidence, enforcement still has to prove the violation, for example by showing that the paid price is consistent with the price of dumping. Since single cases often take up all available resources, comprehensive tracking of waste exports in sample sizes large enough to find the proverbial 'needle in the haystack' is beyond reach even for the EPA. Therefore, enforcers have to rely on confidential information to initiate the investigation, especially when multiple parties are involved in the fraud.

Tracking for voluntary monitoring programs

In the absence of stringent regulation of waste exports, a number of voluntary certification programs emerged. E-Stewards[21] is one such certification program for recyclers who can demonstrate that they do not engage in waste exports. The certification is attractive for recyclers, since it gives them access to high-profile clients: corporations with recognizable brands have a high incentive to work with certified recyclers, since they do not want to risk any of their waste showing up in the wrong place. However, certification programs can be gamed, for example by keeping double books for the yearly audits. Therefore, electronic waste tracking and unannounced site visits are among the additional measures contemplated by program administrators.

A second group of industry-initiated voluntary monitoring programs address the issue that regulatory compliance is not enough to insure a company against subsequent legal problems. The enforcement of environmental violations against RCRA is based on the concept of strict liability, meaning that companies are also liable for their waste management contractors and their actions, which they might know about. The CHWMEG Waste stewardship program provides supply chain monitoring, to allow companies to monitor their contractors and their facilities. CHWMEG it is different from certification programs such as e-Stewards, since it keeps the findings confidential and excludes NGOs and governmental organizations from membership. The program's non-advocacy stance means it does not interfere with enforcement, does not publicly approve or certify, instead only indicates whether a facility has been reviewed or not in its public database. In the context of stewardship

[21] http://e-stewards.org/

programs, waste tracking can play an important role for supply chain monitoring, for example by including the possibility of sporadic monitoring experiments into waste management contracts.

From the perspectives of the regulator and enforcer, voluntary programs are a mixed blessing: it is important to encourage industry to enlist in certification programs, but some skepticism of a greenwashing remains. Some companies who were convicted of environmental crimes had audits on their books. A possible approach would involve mandated industry programs, in which industry has to acquire certification from a third-party independent agent. The role of government is to monitor the certifier, and if needed, punish the violator. Such a more nuanced system would provide more accountability compared to the current situation in which the whole burden of control and enforcement rests on the shoulders of the EPA.

Tracking as an evaluation and education tool for municipal services

The insights from a waste tracking study could help a local government to calibrate their recycling system, for example defining which materials should be collected, how they should be collected and subsequently treated. An overly ambitious recycling system with too many recyclable items on the list can backfire, if it turns out that the municipal system cannot handle the complexity of the different recycling streams. Seattle, for example, has defined a long list of items that require special treatment, which resulted in confusion of the residents, while exceeding the capabilities of the local recycling industry.

A recent episode highlights that even at the global scale, the collection mechanism is of crucial importance. In April of 2013, the Chinese government launched the "Operation Green Fence," rigorously enforcing quality standards for imported recyclable materials. Random inspections of imported recyclables at the ports of entry resulted in the rejection of the whole shipload, if a single bale of recyclable materials does not comply with quality standards. After a number of recyclers in the US were affected by the operation, the low quality of recyclable material resulting from single-stream and mixed stream collection has increasingly raised questions about these collection systems and highlighted the disadvantage of single stream collection in terms of achievable purity compared to source separation (Recycling Today 2013).

For the recycling industry, the behavior of clients including citizens and businesses has a significant impact on the performance of recycling. The presence of food waste in a recycling container turns recyclable materials into garbage. People have to understand how the system works, and how materials should be prepared for recycling - which materials go into curbside, which into drop-off.

Waste tracking would allow explain how the system works to clients. In tis case, the tracking data would have to be augmented with additional information such as: why does transportation stop at a certain point, what happens to it? Once a bale is purchased, what happens to it? Companies such as Waste Management record data extensively, including information about all inputs and outputs. However, it can only capture what the clients do with their materials. To get an accurate picture of the lifecycle of products, the information has to be matched with data from manufacturers.

Conclusion

According to the recorded data, transportation distance seems to play a minor role in the environmental impact of a discarded object as long as the distance stays in the range typical for curbside recycling and landfilling. This also seems to be the case for the location of disposal: while location has some influence on the duration of the waste removal process, it has little influence on the transportation distance involved. In both cases, the null hypothesis holds. What stands out, however, are the transportation distances of electronic and household hazardous waste, which are significantly longer by orders of magnitude. This finding confirms the popular assumption that toxic items are associated with the longest transportation distances. This can be attributed to the more complex collection mechanism and the geographic distribution of specialized treatment facilities. Seattle relies on the participation of residents and recommends Electronic and Household Hazardous Waste to be brought to transfer stations or to retailers, while banning these items in curbside collection (Seattle Public Utilities 2009). As a result, these items are often shipped by mail, either by the resident or by the retailer, to the often-remote recycling facilities. However, the postal and courier services used by Mail-back and take-back programs are not optimal for transporting waste. The data set shows many examples of waste items shipped by airfreight, which results in a higher environmental impact than necessary. This leads us to the conclusion that in some cases, long transportation distances involving multiple modes of transportation can neutralize the benefits of recycling. While take-back programs promise valuable benefits such raising recycling rates and therefore preventing the environmental cost of disposing toxic materials in MSW landfills, our findings call for a close investigation of transportation alternatives within these programs.

Since WARM, the widely used waste impact model from the EPA, does not account for long distances with mixed mode of transport, this is a significant finding. This underlines that hazardous and electronic wastes deserve special attention in future investigations.

The collected data also shows that the quality of waste systems varies with geographic location. Especially the more rural municipalities, remote from central Seattle have higher odds of an item ending up in a landfill rather than in a recycling facility. While the small sample size did not allow for the comparison of a large number of cities, this would be an important area for future studies. In this respect, the method used in Trash | Track project provides a robust approach of investigating the quality of municipal collection and removal systems.

In conclusion, the Trash Track study provides empirical data and a method for evaluating the efficiency of removal systems and waste stewardship concepts. The collected data can support decisions whether it is worth sending a specific waste item to a remote specialized treatment facility or to dispose it locally. The study provides previously unavailable data about long waste removal distances involving multiple modes of transportation and shows indicates a direction for future inquiries – a closer investigation of the collection mechanisms for specialized materials including electronic and hazardous wastes – materials of high value, but also of high toxicity, costly to recycle, but also open for remanufacturing and reuse.

The question of the optimal collection mechanism brings into focus participatory approaches for collecting specialized types of waste that are too thinly distributed to lend themselves to centralized collection mechanisms. The capacity of the tracking method to create a dynamic visualization of the waste system was appreciated by the volunteers and hints at possibilities for the design of these participatory collection systems.

Perhaps the most important application of tracking is in the context of social accountability initiatives – the capacity to observe an elusive system without access to internal information. Even with small sample sizes, it enables citizens to monitor waste systems, and contribute to making urban services more accountable.

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Appendix

Table 12 Number of deployed sensors reporting valid traces, sorted by trash type

Trash Type	Freq.	
Plastic other	198	**
Cardboard	109	****************************
Plastic bottle	108	***************************
Textiles	60	***************
Scrap metal	52	*************
E waste other	50	*************
Glass jar	43	***********
Mixed	41	**********
PCP carton	35	*********
Plastic bag	34	*********
Paper other	33	********
Corrugated box	31	********
Steel can	31	********
Aluminum	30	********
Cell phone	27	*******
Periodical	27	*******
Styrofoam	24	******
Shoes	23	******
Glass bottle	22	******
Alkaline battery	18	*****
PCP other	17	****
CRT	14	****
Book	13	***
Ceramics	13	***
Fluorescent bulb	12	***
Li battery	12	***
PCP cup	12	***
Printer cart	12	***
Hazard other	9	**
Wood	9	**
Computer	8	**
Spray can	8	**
Rubber	5	*
Furniture	4	*
NiCd battery	4	*
Tire	4	*
Total	1,152	

Table 13 Spot Market Value of Scrap Materials (Source: Spotindex.com)

trashType	trashDisposal	toxineLevel	spotValue	
alk batt	special disposal	universal waste	40	$/ton
aluminum	single stream recycling	inert	1420	$/ton
appliance	special disposal	hhw	175	$/ton
book	single stream recycling	inert	85	$/ton
candles	waste	inert	<0	$/ton
cardboard	single stream recycling	inert	126	$/ton
cell phone	special disposal	hhw	1900	$/ton
ceramics	waste	inert	<0	$/ton
corr box	single stream recycling	inert	126	$/ton
crt	special disposal	universal waste	43	$/ton
computer	special disposal	hhw	175	$/ton
e waste other	special disposal	hhw	31	$/ton
f bulb	special disposal	universal waste	<0	$/ton
furniture	waste	inert	<0	$/ton
glass	single stream recycling	inert	3	$/ton
glass bottle	single stream recycling	inert	3	$/ton
glass jar	single stream recycling	inert	3	$/ton
handheld device	special disposal	hhw	1500	$/ton
hazard other	special disposal	hhw	<0	$/ton
i bulb	waste	inert	3	$/ton
laptop	special disposal	universal waste	175	$/ton
li batt	special disposal	universal waste	1300	$/ton
mixed	waste	inert	<0	$/ton
ni batt	special disposal	universal waste	154	$/ton
organic other	compost	inert	5	$/ton
paper other	single stream recycling	inert	61	$/ton
pcp carton	single stream recycling	inert	49	$/ton
pcp cup	single stream recycling	inert	102	$/ton
pcp other	single stream recycling	inert	49	$/ton
periodical	single stream recycling	inert	104	$/ton
plastic bag	single stream recycling	inert	0	$/ton
plastic bottle	single stream recycling	inert	460	$/ton
plastic other	single stream recycling	inert	140	$/ton
printer cart	special disposal	hhw	0	$/ton
rubber	single stream recycling	inert	5	$/ton
scrap metal	single stream recycling	inert	161	$/ton
shoes	waste	inert	900	$/ton
spray can	special disposal	universal waste	<0	$/ton
steel can	single stream recycling	inert	161	$/ton
styrofoam	waste	inert	<0	$/ton
textiles	waste	inert	570	$/ton
tire	single stream recycling	inert	<0	$/ton
wood	waste	inert	5	$/ton

Table 14 Recorded Distances by Waste Type and corresponding Green House Gas Emissions (assuming a fully loaded 22 ton garbage truck with 6 mpg fuel consumption, distance counting one direction)

Trash Type	Mean Dist. (km)	Mean GHG (MTCE / US ton)	Min Dist. (km)	Max Dist. (km)	Max GHG (MTCE / US ton)	Median Dist. (km)
rubber	11.67	0.001	3.24	34.92	0.002	7.56
spray can	10.94	0.001	0.93	45.1	0.002	5.59
glass bottle	18.4	0.001	2.71	84.07	0.004	9.59
PCP carton	16.39	0.001	1.04	187.6	0.010	7.43
periodical	21.95	0.001	0.9	224.03	0.012	7.02
CRT	49.75	0.003	5.04	239.59	0.013	26.04
furniture	79.46	0.004	4.25	248.54	0.013	32.53
computer	101.24	0.005	0.92	269.4	0.014	17.26
tire	135.7	0.007	2.48	271.68	0.014	134.32
scrap metal	31.98	0.002	0.98	272.49	0.014	12.23
aluminum	32.86	0.002	1.29	274.39	0.015	10.75
PCP other	54.62	0.003	4.13	275.36	0.015	10.11
steel can	28.67	0.002	1.15	281.08	0.015	9.4
plastic bottle	27.15	0.001	0.03	283.54	0.015	10.02
corrug. box	29.49	0.002	0.8	291.05	0.015	10.78
styrofoam	46.33	0.002	0.79	294.96	0.016	8.3
paper other	49.35	0.003	1.16	306.94	0.016	14.02
hazard. other	90.14	0.005	0.52	347.29	0.018	30.93
plastic bag	58.01	0.003	0.21	380.35	0.020	10.03
shoes	58.96	0.003	0.21	431.88	0.023	12.8
ceramics	84.49	0.004	0.82	447.13	0.024	12.09
textiles	70.48	0.004	0.41	459.17	0.024	19.7
mixed	71.5	0.004	0.6	481.59	0.025	14.82
glass jar	50.89	0.003	1.32	488.63	0.026	8.57
wood	92.36	0.005	1.22	515.89	0.027	6.36
PCP cup	76.78	0.004	1.76	529.46	0.028	10.15
cardboard	67.31	0.004	0.02	608.02	0.032	10
book	75.09	0.004	0.49	616.85	0.033	13.63
e waste other	97.91	0.005	0.09	678.07	0.036	25.32
plastic other	61.11	0.003	0.02	2814.8	0.149	10.74
f bulb	313.64	0.017	3.34	3454.86	0.183	21.55
li battery	1246.15	0.066	4.84	3975.58	0.210	141.76
alk battery	458.64	0.024	3.97	4374.11	0.231	18.11
ni battery	1128.47	0.060	6.62	4443.76	0.235	31.74
cell phone	831.14	0.044	5.56	4825.22	0.255	230.72
printer cart	1713.57	0.091	1.16	6151.71	0.325	28.2
Total	113.95	0.006	0.02	6151.71	0.325	11.48

Table 15 Greenhouse gas emission factors used by the EPA WARM model, assuming average transportation distances (Zhao et al. 2009)

Material	GHG Emissions per Ton of Material Source Reduced (MTCE)	GHG Emissions per Ton of Material Recycled (MTCE)	GHG Emissions per Ton of Material Landfilled (MTCE)	GHG Emissions per Ton of Material Combusted (MTCE)	GHG Emissions per Ton of Material Composted (MTCE)
Aluminum Cans	-2.256	-3.717	0.010	0.016	NA
Steel Cans	-0.870	-0.490	0.010	-0.419	NA
Copper Wire	-2.016	-1.352	0.010	0.014	NA
Glass	-0.145	-0.076	0.010	0.014	NA
HDPE	-0.493	-0.383	0.010	0.284	NA
LDPE	-0.625	-0.466	0.010	0.284	NA
PET	-0.577	-0.423	0.010	0.311	NA
Corrugated Cardboard	-1.527	-0.846	0.105	-0.165	NA
Magazines/third-class mail	-2.362	-0.837	-0.084	-0.119	NA
Newspaper	-1.333	-0.763	-0.238	-0.189	NA
Office Paper	-2.183	-0.778	0.505	-0.159	NA
Phonebooks	-1.719	-0.725	-0.238	-0.189	NA
Textbooks	-2.494	-0.848	0.505	-0.159	NA
Dimensional Lumber	-0.551	-0.670	-0.135	-0.198	NA
Medium Density Fiberboard	-0.607	-0.674	-0.135	-0.198	NA
Food Scraps	0.000	NA	0.195	-0.044	-0.054
Yard Trimmings	0.000	NA	-0.050	-0.055	-0.054
Grass	0.000	NA	0.046	-0.055	-0.054
Leaves	0.000	NA	-0.155	-0.055	-0.054
Branches	0.000	NA	-0.135	-0.055	-0.054
Mixed Paper, Broad	NA	-0.956	0.087	-0.166	NA
Mixed Paper, Resid.	NA	-0.956	0.063	-0.165	NA
Mixed Paper, Office	NA	-0.932	0.117	-0.151	NA
Mixed Metals	NA	-1.475	0.010	-0.286	NA
Mixed Plastics	NA	-0.417	0.010	0.296	NA
Mixed Recyclables	NA	-0.784	0.048	-0.145	NA
Mixed Organics	NA	NA	0.071	-0.050	-0.054
Mixed MSW	NA	NA	0.411	-0.038	NA
Carpet	-1.096	-1.969	0.010	0.128	NA
Personal Computers	-15.208	-0.618	0.010	-0.052	NA
Clay Bricks	-0.078	NA	0.010	NA	NA
Concrete	NA	-0.002	0.010	NA	NA
Fly Ash	NA	-0.237	0.010	NA	NA
Tires	-1.094	-0.501	0.010	0.024	NA

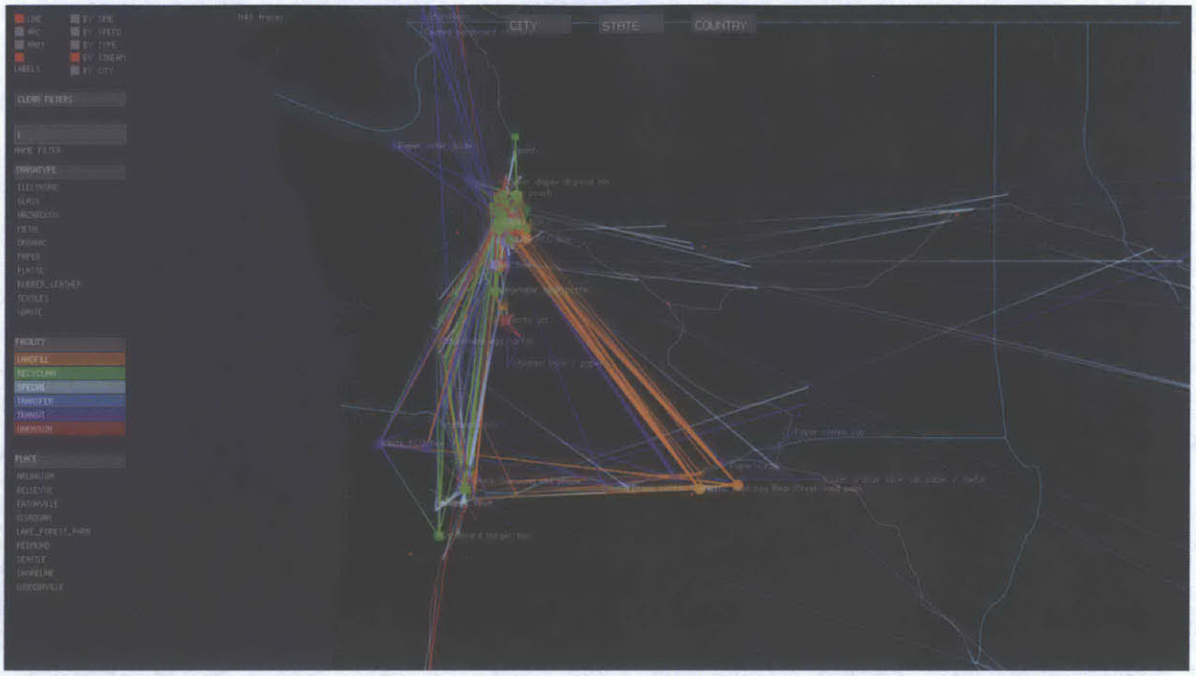

Figure 15 Geographical structure of different waste streams: most prominently orange trajectories lead to landfills, green ones to recycling facilities and light blue ones to special facilities. Visualization: Dietmar Offenhuber

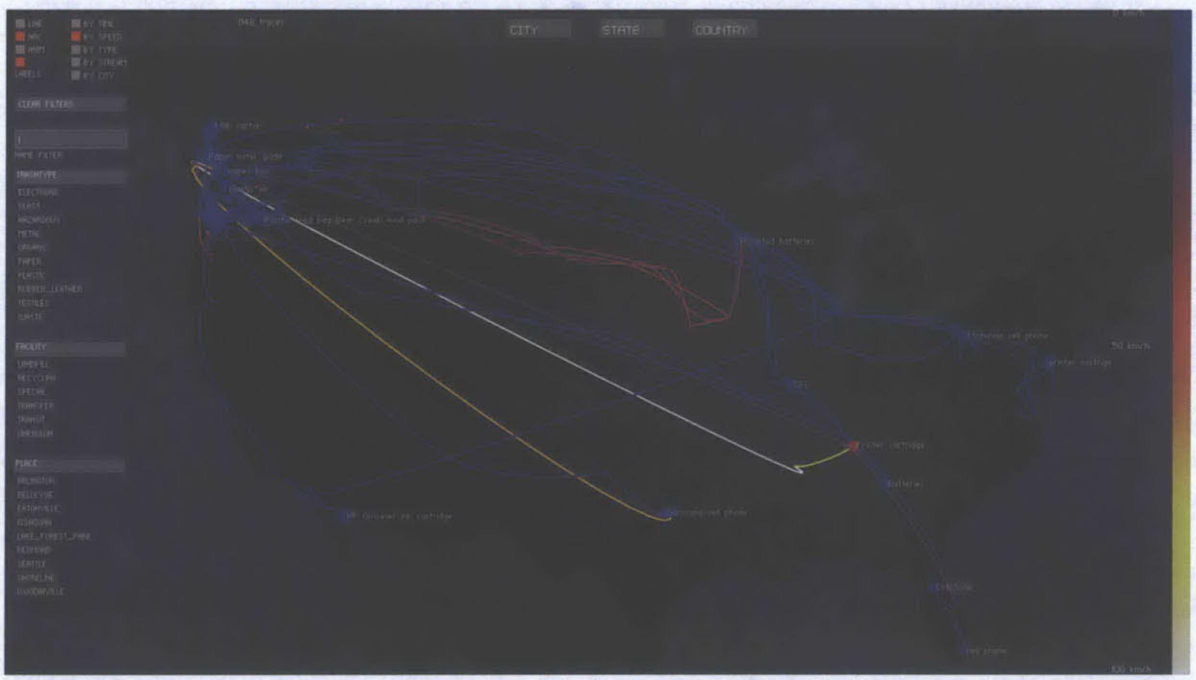

Figure 16 the color represents the average velocity of trajectory segments – sections using airfreight can be made out. Visualization: Dietmar Offenhuber

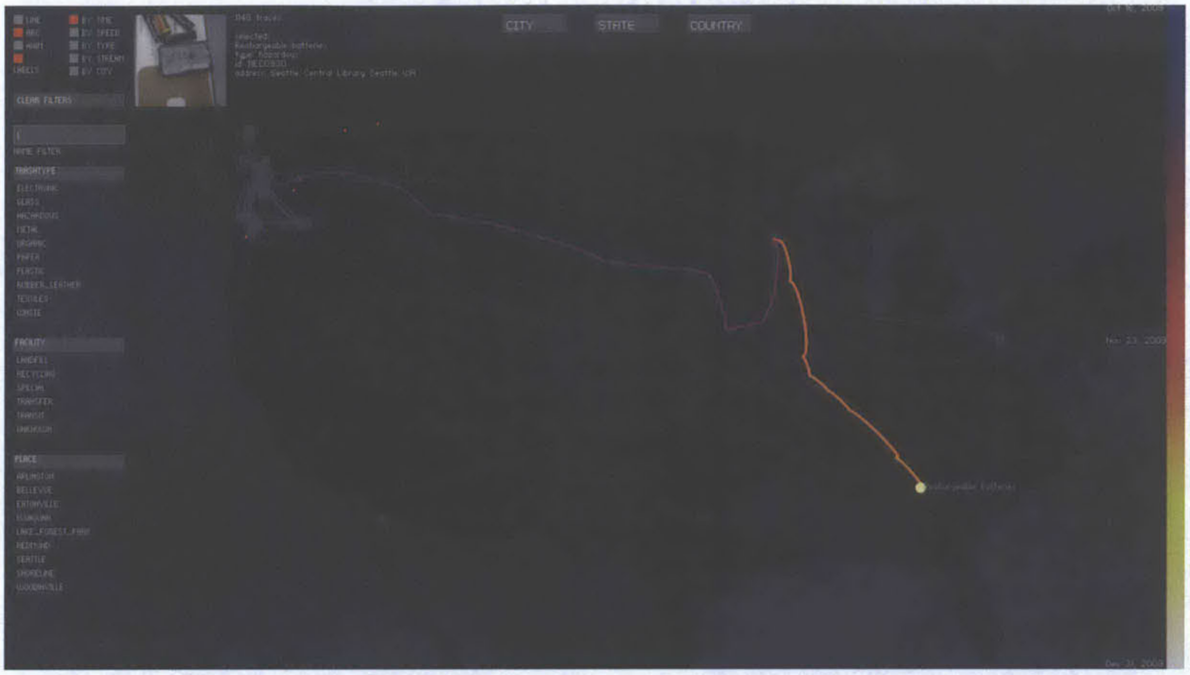

Figure 17 The trajectory of an assortment of small rechargeable batteries, the color represents the date of individual travel segments. Visualization: Dietmar Offenhuber

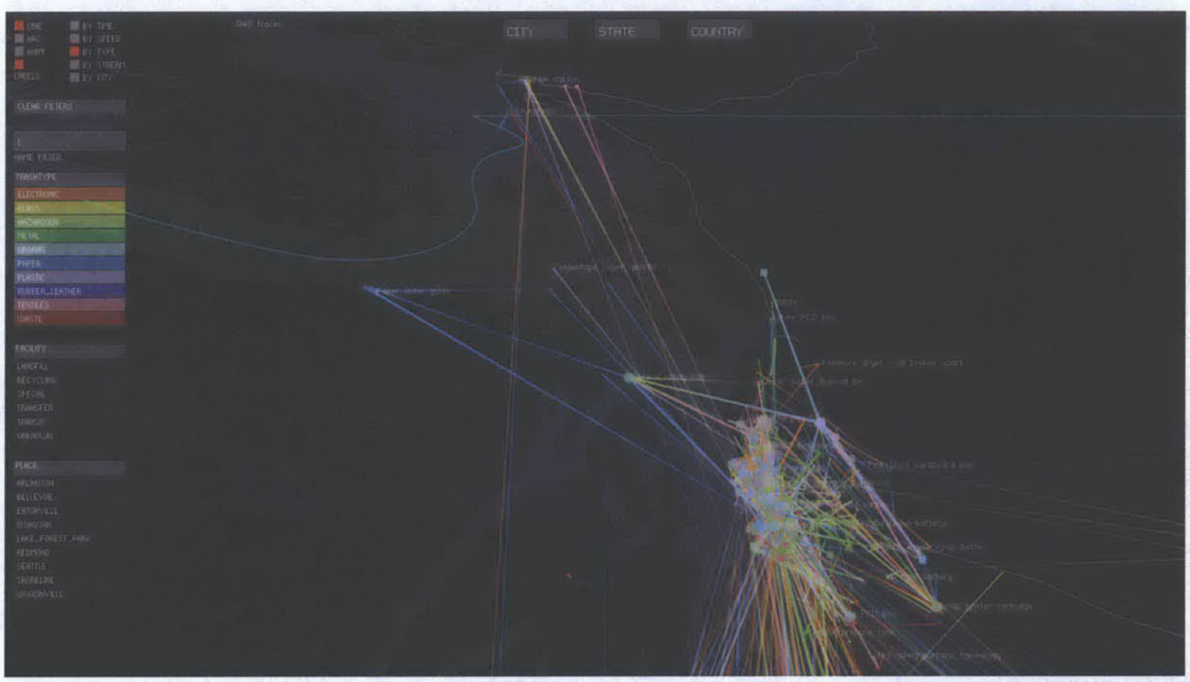

Figure 18 Sensors reporting from waterways in the Puget Sound and Vancouver, CA. Note that localization only works where cell phone infrastructure is available, therefore very few sensors report from within the Sound or Ocean. Visualization: Dietmar Offenhuber

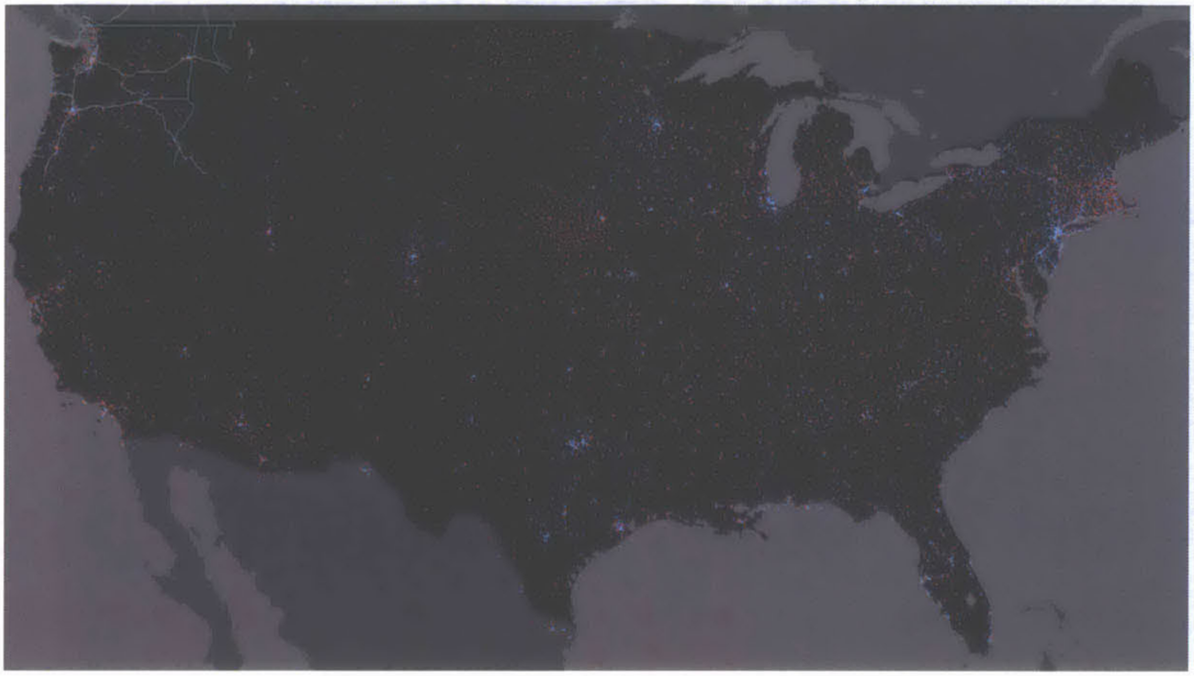

Figure 19 The distribution of landfills and recycling facilities across the U.S. Note the populated areas have a higher density of recycling facilities (blue) compared to landfills (red). Visualization: Dietmar Offenhuber

Table 16 Interview Partners

Jim Puckett, Basel Action Network	Watchdog / NGO
Andrew Lauterback, EPA / Interpol	Enforcer, Regulator
Angela Wallis, Recycling Coordinator, King County Housing Authority	Local Government
Candy Castellanos Public Education & Outreach Manager Waste Management Pacific Northwest Area	Waste Management Industry
Christopher M. Piercy, Recycling Coordinator Kitsap County Public Works	Local Government
Christie Keith, GAIA	Watchdog / NGO / Adovcacy
An administrator from a Waste Stewardship program who preferred anonymity	
Shannon Dosemagen, Public Lab	NGO, Citizen Science

Tacit arrangements – data reporting challenges for recycling cooperatives in Brazil

Preface

The essay is based on data collected during the 'Forage Tracking' project, generously supported by the Carroll L. Wilson Foundation, MISTI Brazil and MIT Global Challenge.
While text and data analysis presented in this essay are the sole product of the author, the author acknowledges the intellectual contributions from the project team members: David Lee: concept, research design, data collection, software development. Lucia Helena Xavier: concept, data collection. Laura Fostinone: concept, local expertise, translation. Julian Contreras: software development mobile app. Rafael Galvão: translation. To recognize these contributions, the plural form was used throughout the essay.

Preliminary findings from the "Forage Tracking" project have been published in the following conference proceedings:

Offenhuber, D., and D. Lee. 2012. "Putting the Informal on the Map: Tools for Participatory Waste Management." In *Proceedings of the 12th Participatory Design Conference: Exploratory Papers, Workshop Descriptions, Industry Cases-Volume 2*, 13–16.

Abstract

In August 2010, the national congress of Brazil passed landmark legislation for solid waste management, the National Policy on Solid Waste (NPSW). The law recognizes for the first time at the national level the work of previously informal waste picker cooperatives and gives them a central role in the national solid waste system. The law also outlines a Extended Producer Responsibility (EPR) approach based on the "polluter pays" principle, which assigns shared responsibility for the whole life cycle of certain products to producers, retailers, recyclers, consumers and the state. The law offers vast new opportunities for recycling cooperatives. However, it also presents new challenges, requiring the cooperatives and associations of waste pickers to professionalize and be more accountable for their operations.

This study answers the following question: how do waste picker cooperatives and associations respond to data reporting requirements from local governments and companies? In addition, how can available location-based technologies support data management and organization of these recycling cooperatives and associations? In answering these questions, the study uses a mixed methods approach using GPS technology both as a data collection device and an interview tool. Based on the method of Participatory Design, the study uses functioning prototypes for developing a smartphone application to support data reporting and organization of waste picker cooperatives. The results discussed in the last section of this paper highlight the potentials, but also the limitations of location-based technologies for supporting and documenting the operations of previously informal recycling cooperatives.

Introduction

On August 2nd 2010, the national congress of Brazil passed the National Policy on Solid Waste (NPSW),[22] a law that has been in the making for twenty years (Brazil 2010). The first national waste management legislation brought a number of significant changes to the management of solid waste and Recycling in Brazil (Consonni 2013). First, it introduced Extended Producer Responsibility (EPR) policy based on the "polluter pays" principle, requiring the comprehensive monitoring of hazardous and electronic waste streams. Equally important, the new law recognizes the role of waste pickers for the waste and recycling system of Brazil, and integrates them into the waste and recycling system. Under the notion of a "shared responsibility for the product lifecycle", the law requires public institutions and private companies to work with the pickers for managing their waste (Ministerio do Meio Ambiente 2010; U.S. EPA 2012). Developed with the involvement of the national movement of waste pickers (Movimento Nacional dos Catadores de Materiais Recicláveis (MNCR 2010)), the law offers vast new opportunities for recycling

[22] In Portuguese Política Nacional de Resíduos Sólidos (PNRS)

cooperatives. However, it also presents new challenges, requiring the cooperatives and associations of waste pickers to professionalize and be more accountable for their operations. Currently, only a few cooperatives meet these expectations and are therefore ready to take full advantage of the new law. Many cooperatives operate without formal planning and accounting, purely on tacit knowledge (Polanyi 1966). They often lack basic education and management experience. This paper investigates (1) the strategies individual groups of waste pickers employ in response to these challenges and explores (2) how technological tools could help to mitigate these challenges resulting from the formalization process.

This study answers the following question: how do waste picker cooperatives and associations respond to data reporting requirements from local governments and companies? In addition, how can available location-based technologies support data management and organization of these recycling cooperatives and associations? In answering these questions, the study uses a mixed methods approach using GPS technology both as a data collection device and an interview tool. Based on the method of Participatory Design, the study uses functioning prototypes for developing a smartphone application to support data reporting and organization of waste picker cooperatives. The results discussed in the last section of this paper highlight the potentials, but also the limitations of location-based technologies for supporting and documenting the operations of previously informal recycling cooperatives.

Background & literature

Brazil has estimated number of 500,000 waste pickers, who make a living by recovering material from waste (Fergutz, Dias, and Mitlin 2011). By collecting over 90% of the material that is recycled by industry, these waste pickers play a central role for the country's recycling system (Medina 2007a, 70). Brazil has a long history of organization and unionization of waste pickers and the formation of recycling cooperatives, dating back to the 1980s (Medina 2010; Gerdes and Gunsilius 2010). Today, many pickers, known as "Catadores de Lixo" have organized themselves countrywide in over 500 cooperatives with a total number of 60,000 members, and formed a national organization for supporting their cause in the political domain. While waste picking is traditionally associated with poverty, it can be an economically sustainable occupation. As of 2009, the members of the cooperative COOPAMARE earn twice the country's minimum wage (WIEGO 2013).

The new National Policy on Solid Waste for the first time recognizes the role of waste pickers for the country's waste system on the national level. Through various provisions such as requiring public institutions and private companies to work with the pickers for managing their waste, the law integrates waste cooperatives into the "shared responsibility for the product lifecycle" (Ministerio do Meio Ambiente 2010; U.S. EPA 2012). The law is the latest step in a long development towards an inclusive waste policy (Dias 2009). As in many other countries, municipalities are responsible for solid waste management. The first municipal laws recognizing informal recyclers emerged in the 1990s in cities such as Belo Horizonte, Porto Alegre, and Diadema. At the state level, legislation mandating inclusion of waste pickers in waste management emerged in the early 2000s, to mitigate the social impacts of closing open dumpsites, where these pickers previously worked. At the federal level, the work of informal recyclers was incorporated into the Brazilian Occupation Classification (CBO) in 2002, and a series of federal laws and presidential decrees made it possible to give recyclers access to collection contracts in federal buildings (Dias 2009, 2–3).

Integrated Waste Management vs. Inclusive Recycling

During the past decades, most developed countries have implemented an "integrated waste management" approach that is a public commitment to landfill alternatives, including industrial recycling or composting (Tchobanoglous, Theisen, and Vigil 1993). In developing and low-income countries, these models are often not applicable due to both economic and social issues: On the one hand, the urban form, public infrastructure, and socio-economic composition do not support efficient collection and sorting technologies. On the other hand, as Anne Scheinberg explains, a modernized recycling approach would exclude the informal sector – waste pickers and informal recyclers, who constitute an integral part of the solid waste system in those countries (2012). A policy response to this issue is what Scheinberg calls "Inclusive Recycling," meaning the inclusion of the informal sector into public waste management and recycling policy. This can take several forms, including requiring companies or the public sector to hire waste pickers, providing access to facilities, loans, technical assistance or supporting waste picker unionization (Scheinberg 2012).

Theories of Informality

The garbage picker may work hard, may have a shrewd eye for saleable materials, may search long for the right buyer; in short, he may be the near perfect example of the enterprising individual. It will not get him far.

(Bierbeck 1979)

A prerequisite for successful integration of the informal sector into the solid waste system is to understand the nature and the extent of the informal sector, as well as its economic impact. The scholarly work on informality has changed substantially over the past decades, shifting from a pessimistic vision to a focus on the informal economy's potential for development (Gerxhani 2004). Different approaches to define and operationalize informality have been used, including the absence of labor registration, the absence of social security, or the employment in micro-firms, excluding independent professionals (Henley, Arabsheibani, and Carneiro 2009; International Labour Office 2013).

In the early post-war period, informal work was seen characteristic for an undeveloped economy, which would over time be replaced by a formal economy through processes of modernization. However, with informality and a lack of formal employment persisting, new approaches became necessary. Today's literature on the informal sector can be grouped into four main schools of thought (Chen 2008; Chen 2012).

The *Dualist School* represents the oldest theory on informality, dividing an economy into a formal and an informal sector. Both sectors are seen largely autonomous from the each other, with the informal sector not only comprising marginalized activities, but also examples of economic success (International Labour Office 1972). The *Structuralist School* introduced by Manuel Castells and Alejandro Portes challenged this notion of autonomy, showing that the informal economy is tightly connected and intertwined with the formal economy and therefore should not be understood as an independent sector. In this relationship, the informal is dependent on the formal economy, the latter producing informality through practices such as outsourcing (1989). Differences can be also found on the question of incentives and disincentives. The *Legalist School,* made famous by Hernando de Soto's analysis of Peru's shadow economy, identifies the legal system as a main driver of informality, pointing to costs and bureaucratic obstacles that prevent informal operations from acquiring a formal status (de Soto 1989). Finally, the *Voluntarist School* emphasizes a voluntary choice between formal and informal forms of occupation and identified economic incentives and independence as reasons why formal workers transition into the informal economy (Maloney 2004).

The nature of the Informal economy cannot be separated from the specific local context. While both Structuralists and Legalists offer a convincing case for explaining specific situations in Italy or Peru, the policy implications of their research could not be more different. Structuralists identify labor market liberalization as a cause of informality, while legalists see the cause of informality in over-regulation, which can be addressed by liberalization. The Voluntarist and the Structuralist perspective offer similarly diverging perspectives. While Structuralists emphasize the dependency of informal employees, Voluntarists focus on independent informal entrepreneurs, who choose informality based on the costs and benefits of formal or informal status. Phenomena of informality remain difficult to generalize and require a careful inquiry into the local setting.

Formalization Models

An inclusive recycling policy requires formal definition and recognition for the various forms of informal recycling. Informal work has traditionally been considered illegal or extralegal – occurring outside legal frameworks, since it is not generating tax revenue or does not adhere to legal standards in the same way formal activities do (Chen 2005). Acknowledging the integral role of the informal economy in the larger economic system, policy in many countries has recently shifted to a more inclusive approach. The social goals of formalization are to provide a safer work employment, socially and economically beneficial and socially respected. While there is a broad consensus about the goals of formalization, the means for reaching these goals are still a matter of discussion. Scheinberg provides a taxonomy of formalization models currently used in different parts of the world (Scheinberg 2012; D. C. Wilson et al. 2012; Scheinberg et al. 2010). She groups these approaches into four different models. In the Service Model (1), a municipality pays the (private) waste pickers for collecting waste and recyclables - often termed as "Pro-poor" Public-Private Partnership (PPPPP). The municipality is responsible for planning and oversight; the pickers are paid for their services. The Commodities Model (2) follows a model of micro-entrepreneurship, focusing on supporting waste picker organizations to become private enterprises, which are able to accept waste management commissions and contracts from municipalities and private companies. Between those two extremes a number of Hybrid Models (3) exist, in which the city and the pickers share responsibilities, but also revenue from valorization, i.e. selling recyclables. Finally, Community-based Enterprises (4) make waste management a concern for the whole community, by incorporating residents, NGOs, picker cooperatives and private actors and corporations. Which model works best cannot always be anticipated, since it is highly dependent on the local context, which may not be completely understood.

Regardless of these organizational architectures, a second aspect is the professionalization of the waste picker's work. In 2001, the Brazilian Ministry of Labor and Employment incorporated the profession of the "Catador de Material Reciclável" (the catador of recyclable materials) into the Brazilian Classification of Occupations (CBO), including around 50 descriptions of tasks carried out under this profession.[23]

While the profession of the waste picker is formally acknowledged, many details of their work remain unregulated. A recent bill to increase regulation of scavenging was not supported by the national movement of waste pickers and subsequently vetoed by President Dilma Rousseff (Senado Federal 2012). Waste picking remains in limbo between formal and informal.

Formalization in Brazil

The size of the informal economy in Brazil is significant; the estimates range from 39% (Schneider, Buehn, and Montenegro 2010), to 47% (Budlender 2011), to 55% and even more, depending on how informality is defined (Henley, Arabsheibani, and Carneiro 2009). The estimated total number of waste pickers ranges from 240,000, based on Census surveys (Budlender 2011), to 500,000, as estimated by the National Movement of Waste Pickers (Fergutz, Dias, and Mitlin 2011).

Brazil implemented policy measures to support the formalization of informal enterprises such as the SIMPLES and SIMEI programs (Brazil 2006), aimed at simplifying program data reporting and taxation. Empirical research shows that the performance of micro-firms both have increased significantly in response to these measures, supporting the voluntarist and legalist perspective of informality (Fajnzylber, Maloney, and Montes-Rojas 2009).

[23] See http://www.mncr.org.br/box_2/instrumentos-juridicos/classificacao-brasileira-de-ocupacoes-cbo

Waste picker formalization in Brazil is closely connected to the cooperative movement. The importance of cooperatives for Brazil's economy is still growing, especially since the global financial crisis (ICA Americas 2010). For waste pickers, the main motivation for creating cooperatives is to become independent from middlemen (Medina 2007b). According to a national law from 1971, cooperatives must have at least twenty members and are not-for-profit entities, meaning that their profits have to be shared among their members; regulations further require accounting, legal representation and reporting to government entities (Brazil 1971). While Cooperatives are involved in a wide range of number of services, it has been argued that they cannot replace public services entirely, due to an inherently lower level of accountability compared to municipal entities (Jascha Benjamin Derr 2013). Encouraging partnerships between cooperatives and private business associations is an important policy goal. An example of such a partnership is the CATA AÇÃO (Collect Action) project is a training program for cooperatives to help them develop economic sustainablility and integrate them better into the value chain. It is the result of a cooperation between the Interamerican Development Bank, several Businesses and private Foundations, the National Movement MNCR, and the national government ("Programa CATA AÇÃO" 2013).

The Research Problem – Questions and Hypotheses

Data collection and data management are central to any modernized waste management systems; Wilson et al. note that the quality of waste data can serve as a proxy for the quality of the waste system in general (2012, 251). However, the availability of data regarding the informal sector is generally poor.

The national solid waste policy grants waste picker cooperatives a special role: they should become stewards of the whole product lifecycle. This means on the one hand recognition, access to municipal contracts, and partnerships with companies who are obliged to work with cooperatives and offer them support. On the other hand, the law requires a considerable amount of formalization and professionalization on the part of the waste pickers. This dilemma becomes apparent in one of the central provisions of the policy – the Extended Producer Responsibility (EPR) principle and the creation of a reverse logistics system – involving transparent logistics of waste management processes - to implement this principle. The core idea of EPR policies is to make manufacturers responsible for the social and environmental costs involved in the disposal of their products. This goes beyond financial compensations for these externalities ("polluter pays"); the larger goal of EPR is to incentivize manufacturers to implement changes in their product design - for example to make products easier to recycle, or avoid certain packaging materials.

The Reverse Logistics is conceptualized as a shared responsibility between producers, retailers, recyclers, and consumers, negotiated in sectorial agreements. These agreements make it necessary to collect information about a product's end-of-life treatment options and measure their performance, including mass balances for lifecycle assessment and tracking information for capturing material flows. This requires rigorous data collection and process tracing on the side of the waste management and recycling industry, as specified in the NPSW (Brazil 2010).

This data collection requirement for the recycling industry also affects the cooperatives, which supply material to these companies. As a result, well-documented material becomes more valuable, and the supply of such material from cooperatives becomes an important factor for recycling companies and commercial haulers. As can be easily imagined, the data collection and reporting present a considerable burden for the cooperatives. Currently, there is little incentive for the cooperatives to go this route. Collecting electronic waste is still unattractive for the waste pickers, as the recycling market for electronics is not yet fully developed in Brazil, and therefore yields little profit for the collectors. This can however be expected to change, with Brazil currently being the fifth biggest electronic market after China, the USA, Japan and Russia (Streicher-Porte 2009). Another obstacle is the large number of orphaned products on the market, whose origin cannot be accounted for, since these objects have been passed on several times within the community (Scartezini 2013; Consonni 2013).

While the information requirement of EPR legislation presents a specific case, it highlights a larger problem. Many waste pickers have acquired the professional knowledge necessary to operate an association or cooperative, but accountability and data reporting remain a challenge in an environment where basic education is often lacking. Pilot projects aimed at developing skills of accounting, including keeping track of work hours and the amount of materials sold, are still at an early stage (ITCP-FGV 2012).

The main question investigated in this study: which challenges do waste picker cooperatives and associations face in formalization process with regard to data management, and how do they respond to these challenges? And the second question: how can available location-based technologies support data collection and organization of recycling cooperatives and associations?

Hypotheses

The paper explores the hypothesis that location-based technologies can be an appropriate tool to mitigate the burden of data-collection and data management for recycling cooperatives and associations. While it can be expected this technology to be unfamiliar and maybe intimidating for the waste pickers, many of these thresholds can be mitigated by working with cell-phones the waste pickers are already familiar with. Under such circumstances, we believe that location-based technology can have a number of positive effects: First, it is plausible to expect that the process of data collection has educational value for the cooperatives, by allowing them to monitor and reflect upon their operations. Second, we expect to have the generated data an intrinsic value for the cooperative, both externally for fulfilling data reporting requirements, and internally, for documenting knowledge, supporting coordination, measuring performance and creating actionable operational data. Third, we hypothesize that both the process of data collection and the collected data itself can benefit the whole community of waste pickers, if shared among the cooperatives. In our interviews, we also explored the alternate hypothesis that cooperatives resist collecting and sharing data, because they fear exposing critical knowledge, which could be taken advantage of by someone else.

These hypotheses guided the design of the initial software prototypes and translated into a set of requirements:

- The tool should offer a low threshold of participation, simple in its structure and presentation, run on cheap hardware, and minimize the use of text.
- The use of the tool should not disrupt the daily practices in the cooperative.
- The system should be designed in a way to support the learning about involved technologies by using them
- Its data output should reflect the cooperatives activities and therefore contribute to establish awareness.

Methods

This study uses a mixed methods approach involving semi-structured interviews, surveys and participatory design using functioning prototypes. Scavenging is a traditionally difficult field of research due to a lack of reliable data, the invisibility of the investigated processes and the vulnerability of the subjects. Martin Medina provides a framework for investigating scavenging, covering both qualitative and quantitative aspects (Medina 2007a, 108). His recommendations for research design place emphasis on the linkages between different actors participating in the value chain, and their patterns of operation. This paper follows his recommendations of research design and topic selection, keeping in mind that the population of recycling cooperatives researched in this study show a high degree of organization and technical literacy compared to most informal scavengers.

A novel methodological aspect of this study is the emphasis on the spatial dimension of scavenging operations, which has been largely neglected by previous studies. Location-based technologies such as GPS trackers, GPS loggers and finally cell-phones similar to the devices carried by manual collectors have been used to map collection routes. The collected traces were subsequently used as a prompt for in-depth interviews with the collector for gaining insights into the motivations for the collector's spatial decisions. Beyond valuable spatial information and logistic parameters, this approach allowed us to investigate other aspects, such as the collector's attitude towards and familiarity with technology, or the degree of information exchange within the cooperative.

The second goal was to explore the potential of these technologies not just as a research tool, but also as a tool for the cooperative to improve their operation. Waste picker cooperatives are highly specialized communities of practice (Lave and Wenger 1991). Every new process, every adaptation of technology has to integrate with existing practices. This was addressed by conducting Participatory Design workshops with the cooperatives. Both a research and a design method, Participatory Design is a self-reflexive approach to design, usually applied to technical systems, which involves all stakeholders in the design decisions and setting of goals (Kensing and Blomberg 1998). PD acknowledges the tight entanglement of technical systems with human practices; the goal is not only to reach a design solution that addresses the practices and interests of all stakeholders, but also to use the design process as a vehicle to investigate the practices themselves.

The Research subjects are cooperatives and associations founded by previously informal recyclers in Brazil. Brazil serves as an ideal case study because of its long history of organized and unionized waste picking, which has led to a large amount of experience and variety of organizational forms. A second reason was the implementation of a new National Solid Waste Policy, including the informal sector. We chose two cities for our investigation. First, São Paulo as the city with the oldest and most established recycling cooperatives (COOPAMARE and CRUMA). The second city is Recife in the northeastern state of

Pernambuco, an economically less developed area where waste pickers are currently in the process of forming a network.

In our work with the cooperatives, we have followed these five steps:

1. Selection of cooperatives
2. Focus-group interviews with cooperatives on site of their facility
3. Spatial mapping of their collection operation
4. In-depth interviews with individual collectors and leaders
5. Participatory Design workshop with researchers and members of the cooperative

After the cooperatives included in the study were selected, the next step involved assessing their current operation. This involved site visits, interviews with both leading and non-leading members of the cooperatives. The spatial extent of their collection activity was delineated and annotated on a printed map. This step was followed by equipping the collectors with location sensing devices to acquire accurate geographical information of their collection routes. As a fourth step, we would discuss the acquired traces with the cooperatives to how well they corresponded their own knowledge of the collection, and to acquire additional information about specific spatial decisions. In a last step, multiple members of the cooperative were gathered in a Participatory Design workshop to collect feedback about the usability of the technology, and generate concrete application scenarios and new ideas for improving the application.

Software prototyping and Participatory Design

Participatory Design approaches are first driven by practical results. To initiate the discussion, we developed functioning prototypes of location-based applications, which served the function to demonstrate the possibilities of technologies to the cooperative and activate their curiosity. Based on their experience with the prototype, the cooperative was asked to sketch and describe functions they considered useful. The participatory design process was guided by three initial goals: First, to document the routes and areas serviced by individual collectors, compare how routes of different collectors relate to one another, and identify the reasons for the collectors' spatial decisions. Second, to design a mechanism that would improve the communication and data exchange between the cooperative and their clients, including local residents and businesses. Third, to design a data collection approach suitable for documenting the sources of e-waste and other controlled materials sufficient for fulfilling the tracking requirement of the NPSW.

Data Sources and Related Work

Existing quantitative data about recycling cooperatives in Brazil originated from studies conducted by international organizations and NGOs such as WIEGO or the UN (Chen 2005; Scheinberg, Wilson, and Rodic 2010); by Brazilian government organizations (Agência Estadual de Meio Ambiente 2012), and by the private sector. Private data sources include the online data base "Rota de Reciclagem" funded by the Company Tetra Pak, provides information about entities relevant to recycling: locations and contact information for cooperatives, voluntary collection points (Ponto de Entrega Voluntária - PEVs), scrap dealers and businesses relevant for recycling (Tetra Pak 2008). The business association CEMPRE offers an educational kit for creating waste picker cooperatives, as well as a database of recycling companies.

A number of private sector organizations such as the AVINA Foundation[24] or GIRAL[25] offer incubators for cooperative, experimenting with a range of different approaches to support collectors in their process of professionalization. For example, AVINA conducted the development of a management

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[24] See http://www.avina.net

[25] See http://giral.com.br/servicos

software for cooperatives under the name CataFácil.[26] The software, now used and tested in a number of cooperatives in Brazil, is designed to provide data for the mass balance requirement of NPSW by measuring the volume of all incoming and outgoing materials. However, the software does not address the collection process or any other spatial processes.

Overview of the Compared Cooperatives and Associations

The surveyed recycling cooperatives and associations have different histories, but share certain characteristics:

- The occupational definition of the waste picker provides a set of defined professional roles and procedures.
- The pickers are formally organized either in associations - private non-profit entities - or cooperatives - worker-owned, not-for-profit entities, which more regulated than associations.
- The groups have partnerships with both the private sector and local governments. In most cases, resources such as trucks, facilities, machines, or education are provided by companies, while the city facilitates and oversees the partnership. Businesses associations such as CEMPRE[27] (Compromisso Empresarial para Reciclagem - Business Commitment to Recycling) coordinate such partnerships for the participating companies. Public companies such as the National Bank for Economic and Social Development (BNDES) frequently support cooperatives.
- Local and regional governments are providing grants dedicated to education, sustainable development, or housing to cooperatives. Public institutions such as schools, hospitals, or offices are obligated under NPSW to contract cooperatives for recycling management.

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[26] See http://www.catafacil.com.br

[27] http://www.cempre.org.br

Apart from these shared aspects, important differences exist between cooperatives on the operational level, starting with the modes of collection. While smaller groups collect post-consumer material opportunistically from the street, larger groups use a door-to-door collection system using trucks, handcarts, or both. Others collect from a fixed locations and clients such as supermarkets, companies or public institutions, which are generally preferred as material sources. Other collection modes are the collection from drop-off points (PEVs), or no collection activity at all, with material delivered from the municipality or companies. In the latter case, the group focuses entirely on sorting, basic processing and baling of material. Differences may exist in the relationship to companies and the city: groups may sell the processed material to municipalities, to recycling industry or other companies, or to intermediaries, for example junk shops. Such these variations determine the relationship between the cooperatives and the municipality, suggesting different models of formalization. The following section investigates these differences and identifies the advantages and disadvantages for the group.

Table 17 Overview of the analyzed groups

Name	Date visited	Org. form	Founded by	Collection Pattern	Role of City	Who buys material	Formalization Model
Rede CataSampa São Paulo, SP	Jan 2011 Nov 2011	Network of Cooperatives	Cooperatives	n/a	n/a	n/a	n/a
CRUMA Poa, SP	Jan 2011	Cooperative	Collectors	Door-to-Door, PEVs	Provides facility, Facilitator	Recycling companies	Commodities Model
Coop-Reciclavel Guarulhos, SP	Jan 2011	Cooperative	City	PEVs, Door-to-Door	Provides facility, Client	Recycling companies	Service Model / Hybrid Model
COOPAMARE São Paulo, SP	Jan 2011 Nov 2011	Cooperative	Collectors	Clients, PEVs	Provides facility, client	Recycling companies	Commodities Model
COOCARES Abreu e Lima, PE	Jun 2013	Cooperative	Collectors	Door-to-Door	Client	Intermediaries	Commodities Model
COOREPLAST Abreu e Lima, PE	Jun 2013	Cooperative	Collectors	Door-to-Door	Client	Intermediaries	Commodities Model
Pro-Recife Recife, PE	Jun 2013	Cooperative	Collectors	Clients, institutions	Client and Facilitator	Recycling companies	Commodities Model
Verde é Nossa Vida Recife, PE	Jun 2013	Association	Collectors	Door-to-Door	Facilitator for private partnerships	Intermediaries	Commodities Model
ARO Olinda, PE	Jun 2013	Association	City	Door-to-Door	City contracts collectors, oversight	City	Service Model

Cooperatives in Greater São Paulo

CRUMA - Cooperativa de Reciclagem Unidos pelo Meio Ambiente, Poá, São Paulo [28]

History and organization: CRUMA, located in the city of Poá within the metropolitan region of São Paulo, is one of the oldest cooperatives, formally founded in 1996 by a group of waste pickers in an attempt to overcome the dependency from intermediaries. The cooperative played an instrumental role

[28] Roberto Laureano – personal communication Jan 2011

in the foundation of the national movement of waste pickers (MNCR) in 1999 (Fergutz, Dias, and Mitlin 2011).

Collection Pattern: CRUMA, currently consisting of 46 members, collects recyclables in 18 districts of the city, amounting to 80 tons of recyclables per month or 10% of the total waste generated in Poá (Notícias de Poá 2011). The cooperative operates a door-to-door collection system using manual carts and one supporting truck, which has been converted to run on vegetable fuel, the result of a previous cooperation with MIT). CRUMA further operates a voluntary collection point (PEV) for recyclables, and run an e-waste center, which accepts appliances and serves as an educational institution for computer literacy using reclaimed and refurbished equipment. In response to the NPSW, the cooperative prepared a plan for extending their municipal selective collection (Notícias de Poá 2013).

Partnerships and formalization model: Their facility is provided by the city; machines through various sponsorships. Interestingly, CRUMA does currently not have a collection contract with the municipality but works with the waste management company who holds the collection contract for the whole city (CRUMA 2013). The cooperative views this arrangement with discontent, given that the cooperative has to make their income from selling material rather than for the collection itself. Currently, CRUMAs operations are not yet economically sustainable, its members yet reaching minimum wage. CRUMA, however, receives grants from the local and national governments for various environmental and social initiatives. The formalization model can therefore be characterized as commodities based: despite grants and material support from the city, the collection and processing activities are not priced.

Data reporting: Recently, CRUMA started to use the CataFacíl software for data management. The main advantage of this practice for the cooperative lies in the relationship with waste management companies rather than with the city – by being able to provide data required by NPSW, the cooperative gains access to better sub-contracts from companies.

COOP-RECICLÁVEL - Cooperativa de Materiais Recicláveis de Guarulhos, São Paulo[29]

History and organization: The cooperative, located in the city of Guarulhos, was founded in 2003 inspired by the model of CRUMA and based on an initiative by an individual and the municipality to implement a citywide selective collection recycling system and processes paper, cardboard, plastics, glass, iron, aluminum, e-waste (Silva 2003).

Collection Pattern: With 80 members, COOP-RECICLÁVEL is a large cooperative. The municipality provides a well-equipped facility close to the airport, and is responsible for door-to-door collection, providing two trucks, a driver, and fuel. The members of the cooperative accompany the collection truck, and are responsible for sorting, separating, and baling material at the facility. The cooperative further operates voluntary collection points.

Partnerships and formalization model: The city plays a strong role in the operation of the cooperative, which collects the recyclables from the whole city. For the city, the organizational form of a cooperative has several advantages; it allows the selective collection of recyclables in a city with narrow and partially unpaved streets – an environment where commercial hauling is hardly possible. The format of the cooperative allows the city also to address social issues and take advantage of incentives provided by inclusive solid waste policies. Formally, the cooperative maintains autonomy in their leadership, with the city having no formal influence in the management decisions for the cooperative, which are collectively made by the cooperados in a weekly plenary meeting. Nevertheless, a public official of the municipality has an office on the site of the cooperative. The central role of the city indicates a service-model.

Data reporting: Oversight, route planning and data collection are in the hand of the municipality, who provides all necessary logistic services for the cooperative.

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[29] http://www.rotadareciclagem.com.br/cooperativa/6845
http://www.coopreciclavel.com.br/

COOPAMARE - Cooperativa de Catadores Autônomos de Papel, Papelão, Aparas e Materiais Reaproveitáveis, São Paulo

History and organization: Coopamare is the oldest recycling cooperative in São Paulo, founded 1989 through a project of the Catholic Church to address homelessness. Before its formalization as a cooperative, the founding members ran an informal association of waste pickers since 1986. Like CRUMA, Coopamare is closely connected to the National Movement MNCR. Typical for the first generation of recycling cooperatives with a strong political awareness, the principles of autonomy, self-management, and organization are of main importance.

Collection Pattern: The cooperative runs a private collection system servicing individual clients and uses two trucks holding three and five tons, one of which they use to collect material up to three times a day - as of November 2011, the cooperative had only one member holding a drivers license. COOPAMARE collects from several public institutions in the city, as well as large companies such as the supermarket chain Pão de Azucar. Electronic waste is collected and dismantled on the site. The cooperative also collects from drop-off points near the cooperative and accepts material drop-offs at the cooperative from residents, businesses, and other collectors. There is generally more material available than they can process. Due to a shortage of labor force, the cooperative had lost a high-profile client and has to occasionally decline other potential customers.

Partnerships and formalization model: Coopamare has has several partnerships with private and public entities. The prefecture provides the facility, located underneath the freeway viaduct Paul VI in Pinheiros (see Figure 20). Companies have sponsored equipment, and NGOs are involved in educational and social projects. The cooperative is taking advantage of municipal and federal grants, recently for a construction project to provide housing for collectors closer to the cooperative (many collectors live at the outskirts of the city, and have commutes of multiple hours).

Many aspects of the cooperative's operation are highly formalized. The cooperative sells their material directly to recycling companies, making it a good example for the commodities model. The facility is equipped with modern sprinkler systems mandated by security regulations. However, there are also many informal aspects to the cooperative. A small group of manual collectors does not participate in the coordinated truck collection, instead collect, bale and sell their own material because they can earn a higher income than the rest of the cooperative.

Data reporting: Data reporting is facilitated through a lawyer, but management of the cooperative has many informal aspects. Truck routes are informally planned and documented only in hand-written journals by the driver. The manual collectors working on their own account and the driver do not formally coordinate their activity. The Cooperative is well equipped for the implementation of the new law, but faces other challenges: they operate in a central area of the city that is highly attractive for private recycling companies. It can be expected that COOPAMARE will face increasing competition in the future.

Figure 20 View of the COOPAMARE facility, located under viaduct Paul VI in Pinheiros / São Paulo, Nov. 2011, photo by the author.

Cooperatives in Abreu e Lima

COOREPLAST - Cooperativa de Reciclagem de Plástico LTDA, Abreu e Lima, Pernambuco and COOCARES – Cooperativa de Catadores de Materiais Recicláveis Erick Soares, Abreu e Lima, Pernambuco

The neighborhood Fosfato in the town of Abreu e Lima, a one-hour drive from Recife, is the home of two recycling cooperatives, located next to each other. The two cooperatives operate under shared leadership: COOCARES - Cooperativa de Catadores de Materiais Recicláveis – Erick Soares, focusing on the materials cardboard, metal, plastic, and COOREPLAST - Cooperativa de Reciclagem de Plástico, only focusing on plastic.[30]

[30] Joint leadership also allows the cooperatives, 12-19 members, to overcome the minimum of 20 members required for a cooperative.

History and organization - COOREPLAST: COOREPLAST was founded by waste pickers in 2004 and, together with COOCARES, went through an incubator program (Incubator Cooperative Popular - INCUBACOOP) from the Federal Rural University of Pernambuco. Facilitated by the University, the association received equipment from an industry sponsorship by PETROBRAS. In 2009, they became a formal cooperative. The facility area of 400 square meters is split between several small buildings on different levels connected through narrow pathways (See Figure 21).

The constraints of the facility are a significant obstacle to a higher level of professionalization. The sponsored machines for processing plastic can currently not be used, due to higher material quality requirements from buyers. PET now needs to be washed before processing, which is done manually by the members in their own houses. Separation and processing is taking place both inside buildings, in its small courtyards but also on the front of the building in the street.

History and organization – COOCARES: The 20 member- cooperative was founded 2003 as an informal association in the course of the organized protest of waste pickers on the open dump site at Inhamã, Igarassu (ITCP-FGV 2012). Joined later by COOREPLAST, the association took part in the INCUBACOOP incubator program in 2003 and became a formal cooperative in 2009. The cooperative processes on cardboard, metal, plastic and sell material to intermediaries. Coocares' facility is slightly smaller than the Cooreplast facility, but are concentrated in one large space, therefore are better suited for organizing work. The workers, coming from the landfill, are less specialized and used to collect and process every kind of material, including textiles or shoes. Coocares' facility is slightly smaller than the Cooreplast facility, but are concentrated in one large space, therefore are better suited for organizing work. The workers, coming from the landfill, are less specialized and used to collect and process every kind of material, including textiles or shoes.

Collection Pattern - both cooperatives*:* The cooperatives operate two trucks, and take weekly turns in collection. They collect in six different neighborhoods (Caetés I, II, II, Caetés Velho, Timbó, Matinha), which are sometimes more than > 30 minutes away from the cooperative. Collection happens in teams of 6-8 collectors, using both a truck and manual carts, covering 63 streets per day. The truck serves as a temporary collection point in a central location of the neighborhood, and teams of 2-3 collectors cover each street with a handcart, collecting material from homes and bringing it back to the truck.

However, it is remarkable that neither cooperative collects in their own neighborhood Fosfato. Ironically, material in Fosfato is collected by informal catadores, who sell their material to intermediaries. The regulations of the national movement MNCR do not allow cooperatives to act as intermediaries and buy from informal waste pickers who are not members of the cooperative. The cooperative sees this regulation as counterproductive, since, they could offer the informal pickers a better price for their material. The informal pickers, on the other hand, refuse to join the cooperative, because they prefer daily pay instead of a salary once per month, and do not subject themselves to regular working hours. This observation by the cooperative seems in line with the voluntarist argument, stating that individual workers make a deliberate choice based on what a formal versus an informal setting would offer them.

Partnerships and formalization model - both cooperatives: Despite its status of a formal cooperative, COOREPLAST still sells most of its material to intermediaries, who offer lower prices but are in the area and accept material even in small quantities. This is a deciding factor, as the cooperative has to sell material as quickly as possible, both because of their lack of storage space, as well as their lack of financial resources that would allow them to wait for a better price from industry. COOCARES sells about 60% directly to industry, and maintains partnerships with Coca-Cola and the PET recycling company Frompet for manual recycling services, for example removing caps and labels from PET bottles brought to the cooperative – a process that currently cannot be accomplished by machines. Both cooperatives confirm that territoriality and availability of material is not the limiting issue, as they could process and sell much more if they more space and labor force. The cooperatives cooperate extensively, by trading material that the other group is better equipped to process.

Many aspects of both cooperatives' operations are still highly informal, given the spatial constraints and the fact that they sell a large part of their material to intermediaries. The cooperatives move towards a commodities model, in the absence of a strong local government that could support them.

Data reporting: Both COOCARES and COOREPLAST engage in accounting and data collection, documenting the working hours of their members and keeping books on the materials collected and sold. This practice is the result of a project with Coca Cola, IDB, AVINA as part of the Cata Açao program.[31] During the 100-day project, the cooperative had to send reports to the project leaders about their progress. As of 2013, the cooperative still maintains the practice of data collection. The cooperative takes pride in their accounting skills: the books are not securely stored in the office, instead placed prominently in the common room, where everyone can see and read them. As the biggest benefit, keeping track of materials allows the cooperative to negotiate contracts with the recycling industry such as Frompet.

[31] http://rapidresultsinstitute.info/what-we-do/projecthighlights/brazil

http://www.cataacao.org.br/institucional/programa

http://www.cataacao.org.br/institucional/resultados

Figure 21 View of a part of the COOREPLAST Facility, June 2013, photo by the author.

Cooperatives in Recife and Olinda

ARO - Associacao dos Recicladores do Olinda, Olinda, Pernambuco[32]

History and organization: Olinda is a historic city protected by UNESCO as a World Heritage Site. In terms of Waste Management, the city faced two problems. First, its narrow streets pose a challenge for mechanized waste collection technologies. Second, 300 waste pickers, many of them children, lived at an open dump close to the city, which was bound to close. To address both problems, the sanitation department of the municipality has started a special project – (Projeto Meio Ambiente e Cidadania or PMAC). The city hires pickers from the landfill in Água Fria for collecting waste in the historic city; creating the Associao dos Recicladores do Olinda (ARO) in 1998. The city provided a space for separating and storage, where the pickers could work and sell material. In 2003 and 2004, the city, driven by the initiative of an individual bureaucrat, wanted to extend the program and provide equipment. However,

[32] Interview Tereza Angelo, Carlos Soares – Diretoria de Limpeza Urbana (DLU)

at that time, the pickers were still ambiguous about the project and keep returning to the landfill, which offered more material within close reach. The landfill was finally closed in 2007, and the national policy of 2010 did no longer allow catadores to operate on landfill sites. At that point, the pilot program to recognize and train catadores to collect recyclables in the city gained traction (Prefeitura de Olinda 2010).

Collection Pattern: ARO collects both recyclables and waste in the old part of the city door-to-door from the residents. The work of ARO encompasses the following aspects: education of residents about recycling, door-to-door collection and the establishment of permanent collection points, the transportation, separation and selling of the material (Macedo and Furtado 2003). Collection happens 3 days a week, using a truck and manual carts, which are uses a vertical cart design adapted for the steep topography of the city. Recyclables are sorted at the facility. Every month, the material is received by a truck from the city, weighted and the revenue disbursed based on the weight. The city is divided into 10 areas, for which contracts to registered associations and cooperatives are provided. ARO also collects during large events such as the famous carnival in Olinda, which poses a special logistic challenge – again, these operations is organized by the city.

Partnerships and formalization model: Most decisions are made by the city, which provides the facility and covers the operational costs – fuel, the truck driver, and truck maintenance. The long-term goal of the city is to convert ARO into an independently operating entity, which would cover also maintenance costs. However, since their members have not yet reached minimum wage, this plan has not been pursued. Formalization follows the service model, with the city being in charge of logistics, organization, and oversight. The city pays waste pickers a subsidized price for each ton of collected recyclables and waste, doubling the amount of what an intermediary would pay. However, the city does not offer other benefits to the collectors. Brazil does, however, offer free healthcare services for all citizens, as mandated by the constitution.

Data reporting: All data collection and oversight is conducted by the city. Officials monitor the work of the pickers, weight material, conduct waste composition studies, and administer questionnaires to the citizens. This annual survey, conducted now for the fourth time, measures the satisfaction of the citizens with the collection system, and collects ideas for improvement. A frequent response from citizens is to hire more catadores and extend collection. However, the city does not survey the exact income of the individual collector. Since the city never evaluated a comparable commercial collection, it not clear, how the costs of the association compare to a commercial service. However, it can be suspected that the latter costs would be significantly higher.

Pró-Recife, Recife, Pernambuco[33]

History and organization: Pró-Recife is Recife's largest cooperative, being the workplace for 41 persons, mostly women. The cooperative located in the Boa Viagem district was founded in 2006 by a public – private partnership between the regional government, the AVINA foundation and the Walmart Company (Walmart Brazil 2009; Walmart institute 2011). As a result of this partnership, the coop received machines, facilities and training.

Collection Pattern: Similar to Coopamare, Pró-Recife operates a private collection service with individual entities. They hold collection contracts for most public buildings and government institutions in Recife and provide collection services for large companies, supermarkets, or other generators of recyclable materials.

Pró-Recife operates two trucks, collecting material from all over Recife on six days a week. Private collection creates logistic challenges, including traffic and driving restrictions, missed appointments and a highly variable amount of material available at each site. A major impediment is created by unpaved streets around the facility, which are regularly flooded and impassable when it rains; during that time, no collection is possible.

[33] Roberta da Santana Pessoa, José Cardoso

E-waste is a major concern for the cooperative. Through their government contracts, they regularly receive waste equipment (See Figure 22), but so far have been unable to make profit from it due to the under-developed electronic recycling industry in Recife. A second issue is created by the reporting requirement of the national policy, requiring the cooperative to document the source of the material in order to sell it for a profitable price. Despite its high intrinsic value, e-waste is currently less attractive for cooperative than paper or PET.

Partnerships and formalization model: The cooperative is one of the winners of the formalization process. Facilitated by state and national policies, Pró-Recife was able to secure many public and private contracts. By being able to sell directly to the recycling industry, they are able to bypass the intermediaries and therefore receive higher prices. The cooperative represents a successful example for the commodities model.

Data reporting: Pró-Recife uses computers to keep track of material volumes and plan their collection routes. However, with their large and sparse collection area, monitoring the performance of collection and yield per collection point is a major concern that remains to be solved. Since prices are negotiated with each client individually, better collection data could help the cooperative to increase their revenue.

Figure 22 E-waste at the Pro-Recife Facility, June 2013, photo by the author.

Associação de Catadores O Verde é a Nossa Vida, Recife, Pernambuco[34]

History and organization: The Association is located in proximity to Pro-Recife in the Boa Viagem district. Nossa Vida, currently operated by 5 people, have a smaller, but well equipped and organized space. The group has existed for 13 years and provided work for up to 20 workers. They received their current space 8 years ago, and are formally registered as an association since 4 years. In this organizational form, they are formally not allowed to sell material, only services. For this reason, they have to keep working with intermediaries, who accept material by the kilo without asking for an invoice.

[34] Edoaldo Francisco de Souza

Collection Pattern: Since the association does not own a truck, they collect from the neighborhood around the facility using manual carts, usually three times a week. Material is collected from the street (6-7 tons per month), from companies and stores and from condo-buildings, yielding a relatively modest amount of 15 tons per month. Each of the four collectors has their own collection strategies. Collectors specialized on different modes of collection. One interview subject collects only from companies: paper, cardboard, PET. Two other pickers collect PET mainly from residential buildings. Since many residents do not separate their recyclables, they have to pick out the PET from the regular waste.

Partnerships and formalization model: The association and its facility was the result of a partnership between the city and a local packaging company. The company provided the facility, and delivers up to 9 tons of material per month to the association for sorting. Becoming a formal cooperative instead of an association would Nossa Vida allow selling directly to industry, and city wanted them to take this formal route. However, the association was concerned that they are not able to recruit and sustain a large enough labor-force. Furthermore, taxes and costs for accounting were seen as an obstacle. For this reason, they kept the status as an association, selling to intermediaries without the exchange of an invoice. The association is therefore still operating in a mostly informal manner. Their formal status tends towards a commodities model; at the same time, the members try to gain more support from the city.

Data reporting: The association sends monthly mass-balance reports to the city specifying how much material they collect. However, the benefit of this practice is not clear, since they sell exclusively to intermediaries. The association sees the reporting as an obligation to provide basic accountability towards the city. The association does not keep copies of the filled out forms they send to the city every month, underlining the impression that the practice has currently limited significance for the association.

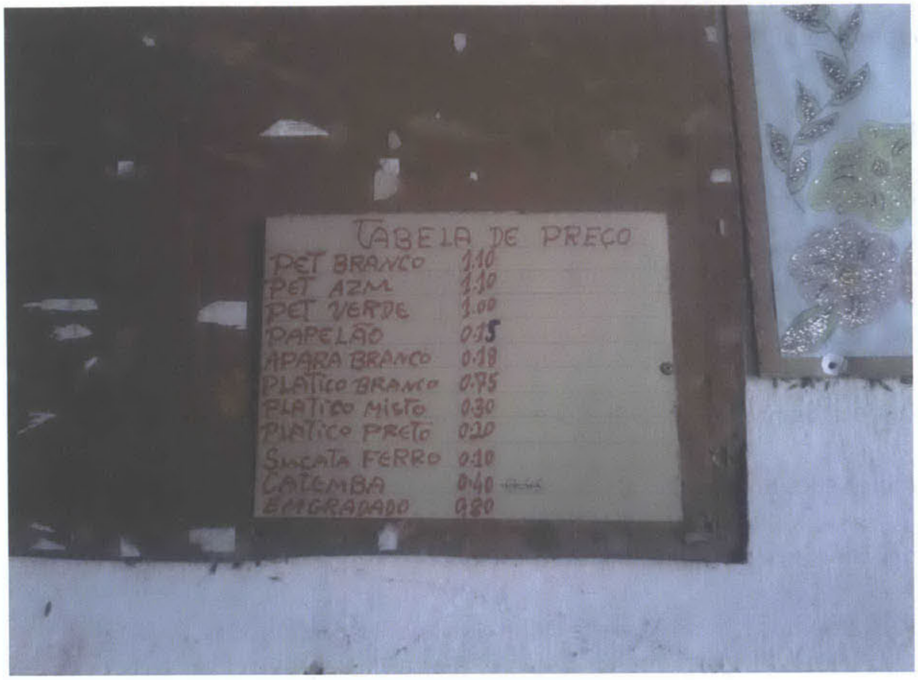

Figure 23 hand-written material pricelist at the Associação de Catadores O Verde é a Nossa Vida facility. Photo by the author.

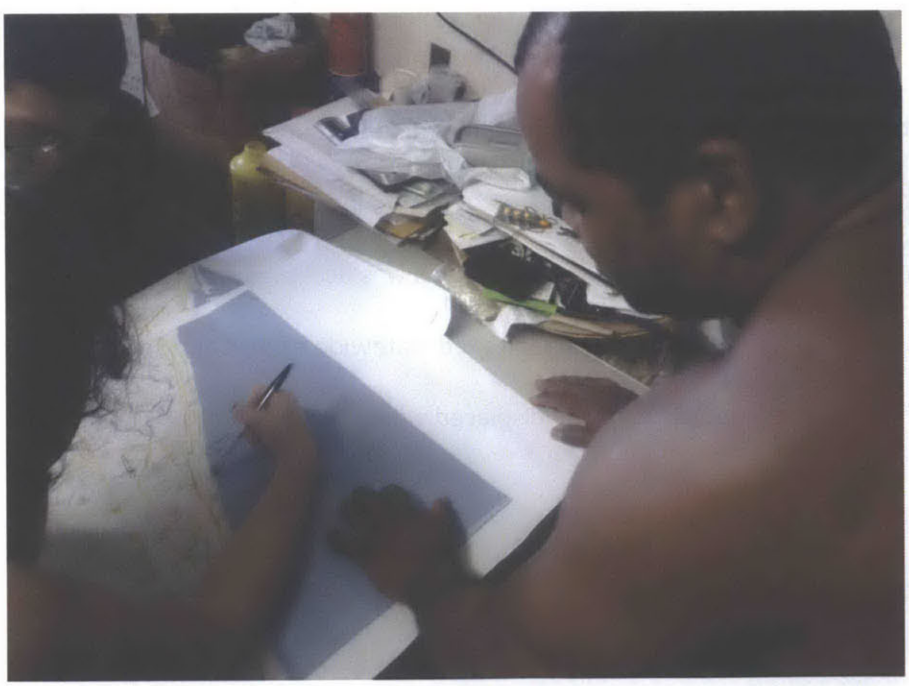

Figure 24 Mapping collection area at Associação de Catadores O Verde é a Nossa Vida, photo by the author.

Data collection from the perspective of the state Pernambuco

The state of Pernambuco implemented its first solid waste policy in 2003. The National Policy of 2010 required states to provide a comprehensive implementation plan until 2012, which the state developed based on its previous policy. The state policy provides substantial monetary incentives for cities to adopt socially inclusive policies – subsidies 25% in first year, 15% - 5 % of the overall budget in the following years (Agência Estadual de Meio Ambiente 2012, 196). Currently, the state government is in the process of collecting data on the characteristics and qualifications of its waste picker workforce. Beyond the observation the state also strives for improvement, planning an incubator for cooperatives, funded by the Secretariat for Economic Development (Secretaria de Desenvolvimento Econômico - SUAPE.)[35]

One obstacle for harmonizing data across the state is the different administrative responsibilities of waste management issues. Waste management is in rural areas frequently administered by the department of agriculture, while in urban areas it normally falls under the department of environmental issues. The modernization of waste management during the past decade, including closing open dumps and unlined landfills, was a state-wide issue that helped integrating the different administrative entities and gave rise to a social policy. Until 2010, the municipal region of Recife, including 14 different municipalities, operated its main landfill in Muribeca, Jaboatão, which was occupied by more than 3000 waste pickers. A series of protests in 2004 by waste pickers initiated statewide efforts and social initiatives were launched to find other occupations for the displaced waste pickers (Melo 2009).

[35] http://www.sdec.pe.gov.br/

Discussion and Results

RQ1 – identifying the challenges of data management

The following section provides a discussion of the observations and insights gained from facility visits and interviews with regard to the first research question: which challenges do waste picker groups face in the formalization process with regard to data management, and how do they respond to these challenges?

The various data related issues observed at the cooperatives and associations can be grouped into three main challenges.

Challenge #1 - quantifying value in the transition from scavenging to public service contracts

The first step for cooperatives that have potentially access to public service contracts is to understand the true value of their service. Based on our observations, this step is less trivial than it might seem. Informal waste pickers are used to collecting in an opportunistic manner, cherry-picking specific materials from specific places, depending on what is most profitable and matches their expertise. This collection strategy can be described through the theory of optimal foraging, a micro-economic model for explaining foraging behavior by taking profit, time and effort into account (Charnov 1976).

Municipal collection is based on very different expectations: The scavengers no longer can only pick what is valuable to them, but have to collect all material in a specific area. While service contracts are generally highly attractive for a cooperative because of the long-term stability they offer, the collection is not necessarily always profitable for the cooperative. Several of the observed cooperatives providing door-to-door collection for the municipality would not reach minimum wages for their members.

The municipalities, often viewing their partnership with cooperatives as a social welfare, do not know the market value of the service either. Municipal officials tend to see the inclusion of waste pickers as a social policy goal, which gives the city also access to federal grants. The economic dimension is ignored, none of the municipal coordinators we spoke to have evaluated the cost of a comparable commercial collection service.

Due to the universal presence of scavengers, waste generators are often framed as 'material donors', a term that can even be found in official documents (Diário de Pernambuco 2013). Interview partners mentioned collection contracts that failed because of diverging expectations between cooperatives and companies, who saw the collection contract as a cost-effective way of waste disposal. Cooperatives, on the other hand are often not aware of their real costs including labor, fuel, and depreciation of machinery. Although many cooperatives are not equipped to provide a reliable city-wide collection system, it can be suspected that cooperatives are underpaid for the service they provide: according to estimates, the same service provided by a company would cost the municipality up to 300 percent more (Fergutz, Dias, and Mitlin 2011, 598). Comprehensive documentation of a cooperative's spatial operations would therefore help measuring the true value of their service.

Challenge #2 – Understanding collection patterns to measure the cost of collection

Every waste picker association or cooperative has an understanding of their collection areas, but this information is rarely documented or shared. Measuring value of service requires also a closer look at the spatial dimension of collection: to provide a way for the cooperative to determine which areas are profitable given the available material, and to provide the municipality with information about where additional services are required. While considerable data has been collected in recent years about Brazil's informal sector, its spatial patterns remain unknown. In the case of waste picking, these patterns can be quite complex. Collection areas of different cooperatives often overlap, with autonomous informal collectors being additionally present. Territoriality among waste pickers is a common theme in the literature, yet it did not seem to be an issue for the cooperatives. At the time of our interviews, more material was available than could be collected, while labor-force and storage space were generally considered the main limiting factors. Because of the number of actors involved in waste collection, the rigid delineation of service boundaries is not necessarily always the best way for defining collection responsibilities in service contracts. This definition, as well as the available information, depends on the pattern of collection (Medina 2000, 54), which includes the following options:

- **Manual and informal scavenging**: Almost no documentation exists. Nevertheless, each collector has preferred routes and schedules, which may involve regular clients, collection points, or streets. The mapping experiments and interviews revealed the variety of different strategies employed by waste pickers. One collector from COOPAMARE specialized on collecting cardboard from a fixed route, which he would follow twice a day. This decision was based on the material's volume, weight, availability, and market price, although he acknowledged that with changing market conditions, his preferences might change. Informal catadores who work alone often specialize on ferrous metals or aluminum, which yields higher prices, but is available in smaller quantities. In the hilly topography of São Paulo, informal collectors often pull their empty cart to the top of a hill and work their way down into lower terrain, to places where junk shops and atravessadores are located. Finally, traffic conditions can determine whether a street is suitable for collection.
- For **private collection contracts**, the level of documentation varies. An association or cooperative has a fixed number of clients, who expect collection services on a more or less regular schedule. Larger Cooperatives use such as Pro-Recife use computers to plan the daily routes, but we also spoke with several cooperative leaders who do not keep written documents about their collection.
- **Door-to-door collection contracts** are usually best defined and documented. Collection may happen by handcart, trucks, or combination of both. In door-to-door collection, the residents

are an important factor – coordination is necessary about timing and how material should be prepared for collection.

Despite having a good understanding of the spatial domain, waste pickers sometimes struggle with documentation of their activities. In one cooperative running a door-to-door system, leaders were not able to identify collection areas on an abstracted map. In another case, routes were planned by one person and documented in a paper journal. Even in a case where routes were planned on a computer, the cooperative leaders noticed large discrepancies between actual and planned routes.

Documenting the actual routes allows measuring the cost of collection and helps to identify ways to improve spatial coordination. During our work with the cooperative COOPAMARE, we compared the patterns of manual scavenging with truck collection (Offenhuber and Lee 2012). At first, it may seem obvious that truck collection is superior to manual collection. However, in the environment of central São Paulo, several factors such as traffic and lack of parking space, narrow roads, a nightly driving ban for trucks all limit the usefulness of the truck. Surprisingly, one of the manual collectors collected and processed twice as much material per capita compared to the rest of the cooperative. By using hybrid collection modes, using both manual and truck collection, cooperatives such as COOCARES can combine advantages and disadvantages of both systems.

Challenge #3 – accountability for business partnerships and regulatory compliance

Recycling associations and cooperatives are subject to a number of legal requirements, but not all of them are clear or enforced. According to the federal law 5764/71, a cooperative has to have a minimum of 20 persons and must meet specific accounting and procedural requirements (Brazil 1971). Both requirements are difficult to apply to recycling cooperatives, which generally have a high fluctuation in membership, and often do not reach the required minimum; this was the case for several cooperatives included in this study. The local governments are aware of these issues, and do not enforce the full set of regulations that apply to cooperatives. This situation is not clarified by the fact that the NPSW prominently features provisions for supporting recycling cooperatives, without clearly defining what a recycling cooperative is.

As a result, recycling cooperatives operate in a somewhat grey area between formality and informality; which severely limits the value of data exchanged between cooperatives and municipalities. The situation of the association Nossa Vida, described earlier, serves as an interesting example of how formalization happens in reality. Their first step from an informal group to a formal association facilitated partnerships with industry, which resulted in a new facility for the association. Yet, this status does not allow them to operate formally, as they are officially not allowed to sell material. When Nossa Vida decided against the suggestion of the city to take the last step of formalization towards a cooperative, the city nevertheless accepted the arrangement, and kept receiving monthly reports about material processed and informally sold.

While for the moment this might be an acceptable solution, it can be expected that after the introduction of the reverse logistics system, these practices will no longer sufficient. Not necessarily because of the cities will demand more clarity: it is the stricter regulation of manufacturers and the recycling industry that will increase the value of data, which will raise the pressure to improve the professional accountability of cooperatives. The introduction of *Bolsa Verde do Rio de Janeiro*, a carbon credit market, which acknowledges waste management practices, illustrates these future developments.[36]

RQ2 – exploring location-based technologies to improve tracking and data management

The Issues identified above underscore the need to new approaches to data collection. In the participatory design part of this study, we investigated location-based technologies for three distinct purposes:

[36] http://www.bvrio.org/

1. To document the routes and areas serviced by individual collectors
2. To improve the coordination between the cooperative and their clients
3. To track collected materials, especially e-waste to implement a reverse logistics chain

The first two points were addressed in the prototype developed with COOPAMARE in São Paulo; the third point was investigated with various cooperatives and associations in Recife.

Part I - COOPAMARE – spatial mapping and co-management

In our work with COOPAMARE in São Paulo, the focus of research laid on a spatial analysis of the collection routes and the investigation of how individual collectors coordinate. In this first example, we used GPS loggers - Sensors that store the sensed location on the device, but do not report their location over the network. These devices were used to record both the routes of manual collectors as well as the trajectory of the truck. Both modes of collection were mapped for slightly over a week. A second part of the mapping exercise involved digitizing a list of clients and collection points as well as the frequency of visitation into a GIS system; this information was available as a hand-written journal from COOPAMARE's truck driver. The resulting maps were contextualized with the recorded traces on a customized web-application based on the Ushahidi platform (Okolloh 2009). This website was only accessible to the cooperative for the duration of the experiment.

The goal of the first participatory design workshop at COOPAMARE was the exploration of how the automatic documentation of collection activity could help the cooperative in organizing their operations. One idea that guided the workshop was a reporting tool, which would allow residents and businesses close to the cooperative to report the availability of material in real-time. The workshop participants included researchers from the University of São Paulo, representatives of the Network of Cooperatives (Rede CataSampa 2008), and all members of COOPAMARE.

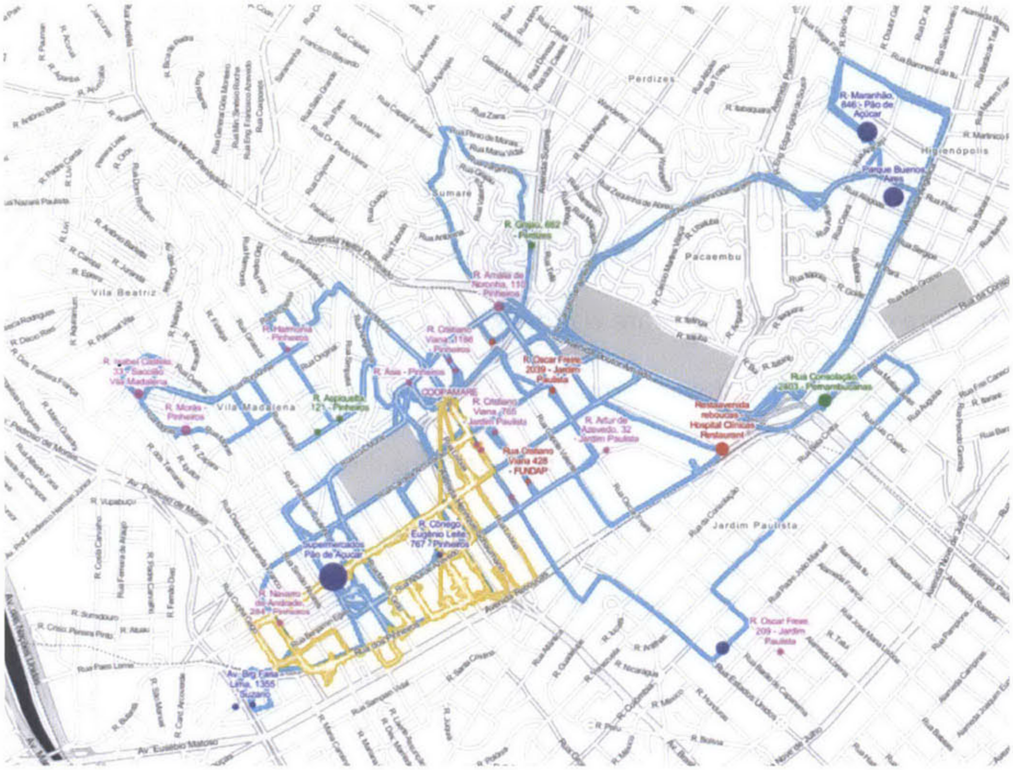

Figure 25 One week of Coopamare Collection activities. Yellow traces correspond to manual collection, blue traces to truck collection. Dots represent different clients, their size the frequency of visits.

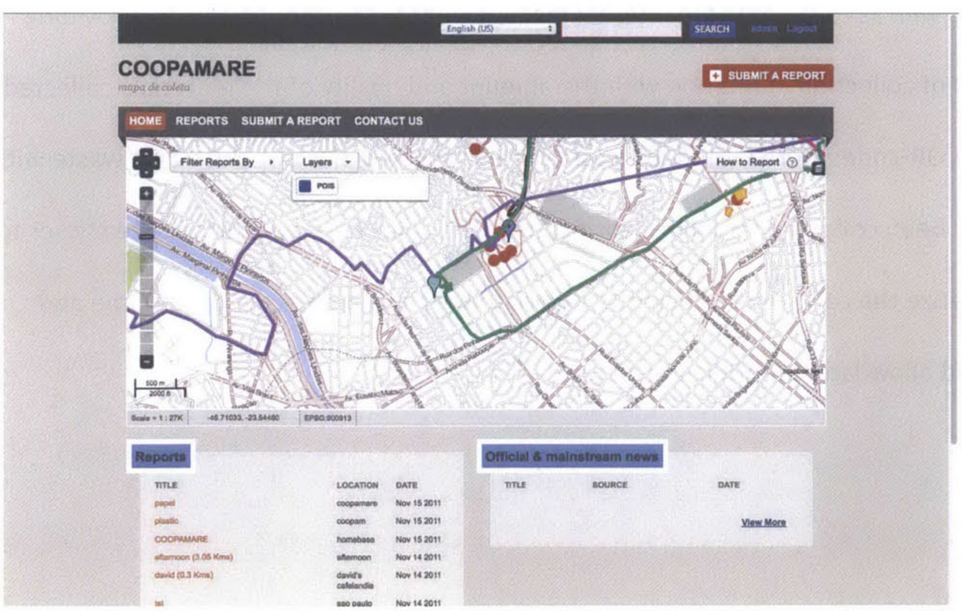

Figure 26 Functioning prototype of the data management tool based on the Ushahidi platform, with actual collection traces and simulated requests from residents.

Recife – Data Reporting tool

In the follow-on research with cooperatives in Recife, the technologies were modified based on the insights from the first participatory design workshop. Instead of using GPS loggers, we developed software, which not only tracked the collection process in real-time, but also allowed the collectors to specify the materials that are collected. The software was designed to run on phones similar to the ones already used by individual collectors. The software prototype, developed for the Android Operating System, allowed the following two operations: (1) continuously tracking the location of the phone and sending this information in real-time back to our server, unless the collector disables the tracking through a prominently placed button. Beyond recording the location, the software also allows to catalog the materials collected (2). To do this, the collector would take a picture of the collected object, optionally tag the object using a 2d-barcode sticker for later identification, and send the information with additional metadata such as time, location, and type of material to the server.

Those two simple features were designed to allow the collector to fulfill the data-reporting requirement of NPSW, as well as to support the internal management of the cooperative by providing an estimate for the costs of collection in relation with the amount and quality of the materials collected.

The stickers with QR-codes were intended to associate a collected piece of electronic waste with the location where it has been collected for later identification. The collector would attach the sticker to an object of e-waste, digitize the code of the sticker to associate the tagged object with the time and location of collection, and allow later identification.

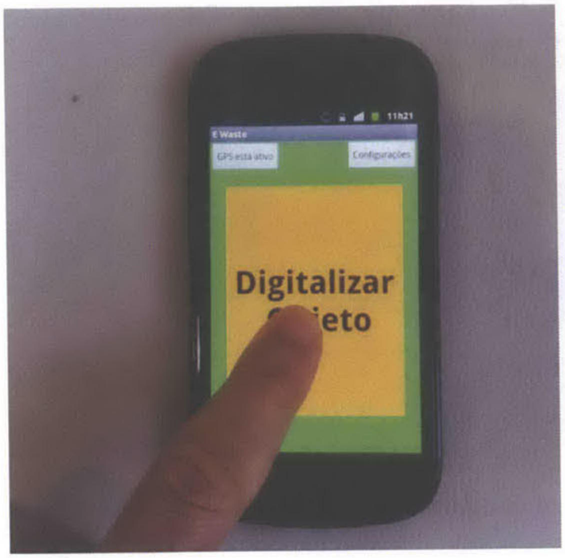

Figure 27 Screenshot of Android application for recording trajectories and documenting collected material. Credits: Julian Contreras, Dietmar Offenhuber

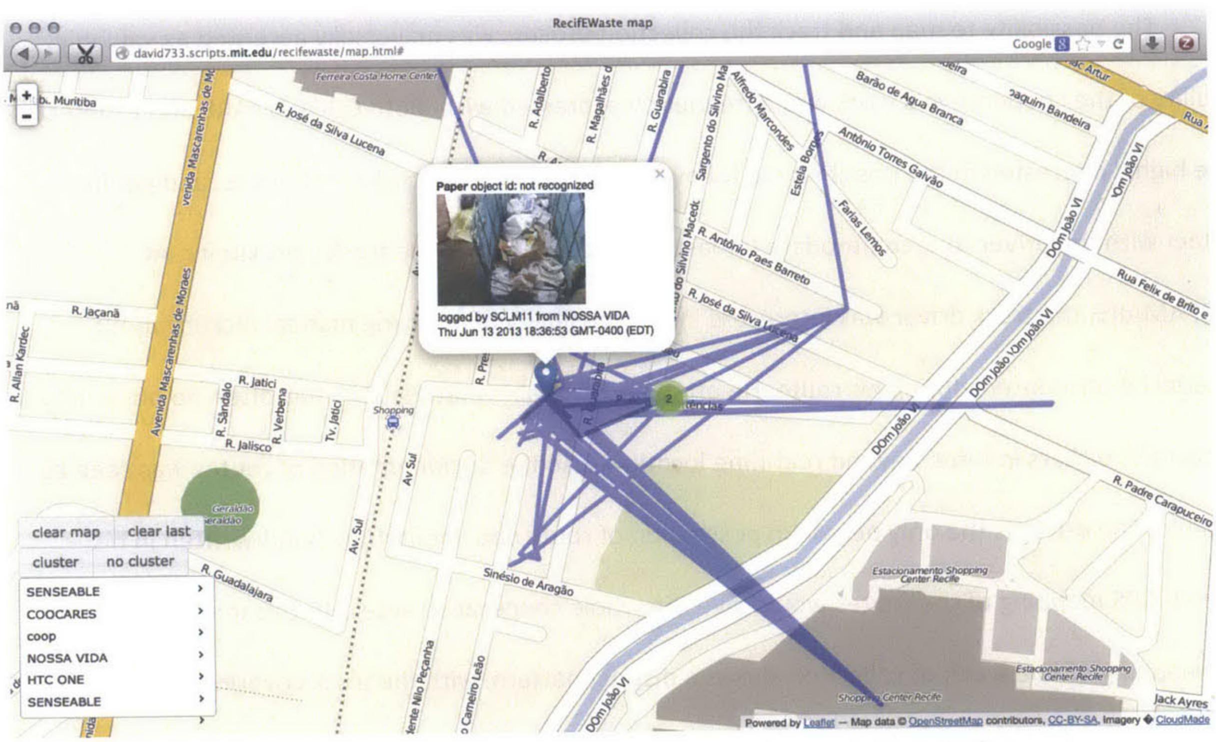

Figure 28 Online map for viewing trajectories and recorded objects. Web application: David Lee

Figure 29 Participatory Design Workshop at Pro-Recife (left) and COOPAMARE (right). Foto: right: Dietmar Offenhuber, left: David Lee

Mapping collection

The possibility to map and track the collection process was universally accepted as valuable. Visibility of the cooperative's work was a frequently expressed wish. Both COOPAMARE and Pro-Recife were highly interested in the possibility to follow the location of the truck in real-time, and get in contact with the driver to accommodate for last-minute requests in the truck's proximity. At COOPAMARE, the truck driver was interested in the possibility of notifying manual pickers about material he encounters during his route. He often finds suitable material, but has often no possibility to contact the pickers in time. Beyond real-time location, also the documentation of routes was seen as valuable. The driver is the only person in possession of route documentation, hand-written in his journal. GPS mapping of the routes would give the whole cooperative access to this information. The GPS mapping of one week of collection shows a distinct pattern, with the truck covering a wide range of destinations, while manual collection happens in a concentrated area (Figure 21).

At Pro-Recife, route-schedules are centrally planned and managed, but the actual routes depend on many different parameters. The cooperative was interested in a way to verify the plan with the actually driven routes, and verify amounts of material collected.

Data exchange: co-management between cooperatives and clients?

As in most recycling systems, the active support of the clients and residents is of central importance. The Cooperatives COOPAMARE or COOCARES spend considerable effort to educate residents about separation and preparation of recyclables. COOPAMARE go as far as distributing printed material in schools. Their efforts have allowed them to reduce manual collection, since residents now drop off material personally at the cooperative, contributing up to 25% of the material processed.

At COOPAMARE individual collectors have regular clients they receive material from. In the subsequent participatory design workshop with COOPAMARE, we explored a scenario, in which residents can inform the cooperative via Internet about recyclable material they have, and schedule a pickup using text messages.

While COOPAMARE is among of the few cooperatives that are technically equipped for this form of electronic communication, the design workshop highlighted other, non-technical concerns. One concern was that the convenience of contacting the cooperative via text messages would increase the number of requests and raise expectations on the side of the residents, which the cooperative might not be able to meet. Another concern was that the use of a mediating technology would likely reduce the number of face-to-face encounters with residents. Through these encounters, the cooperative aims at developing a relationship with clients and residents in order to build trust and educate them how to provide material in order to support material sorting and processing (Offenhuber and Lee 2012).

Data reporting and compliance with legal requirements

Tracking and documenting e-waste collection, early on identified as a potential obstacle for the implementation of reverse logistics, was confirmed by the cooperatives to be a challenge. Cooperatives such as Pro-Recife frequently receive e-waste, such as old monitors or TVs, often without knowing where they came from. Such devices cannot be sold to recycling industry without documentation of their origin. Consequently, these devices have to be sold to intermediaries such as junk shops – for a price that is often lower than that of recyclables such as PET.

Our initial software prototype was based on the idea that the source of e-waste could be documented during collection and tagged with a unique barcode for later identification. To accomplish this, collectors would carry a smart phone with the software we designed, use it to take a picture of the item, and attach a barcode-sticker to it, which is also recorded with the smart-phone application.

After observing how the collectors use this software and collecting their feedback, we adjusted the interface to simplify the process. Truck and manual collection come with different challenges for this approach. In truck collection, the stops at facilities have to be very brief and hurried; to prevent the truck from blocking traffic or the loading dock for too long, the material has to be loaded as quickly as possible. For manual collection, the challenge is security: in Boa Viagem, collectors were reluctant to bring a phone on collection for fear of robberies. Environmental factors (dirt, light, humidity) were also challenging, although collectors wear seldom gloves during collection.

The cooperative Pro-Recife was especially highly interested and offered ideas how to further develop this system. They imagined having a smartphone in the truck, which would record routes, enable two-way communication with the cooperative, and allow tagging of e-waste and a quick estimate of volume for other materials on location. They suggested a module that would automatically compile the data recorded on location into an electronic spreadsheet that would simplify their interaction with material buyers from industry.

Attitudes towards Data sharing and Privacy

Information exchange between informal collectors is both characterized by competition and cooperation.

Collectors typically would withhold information about material they are specialized in from other collectors, but share information about other materials, and especially prices offered by different intermediaries.

In our experiment, the participants viewed information exchange among different cooperatives generally as desirable and a prerequisite for the planned foundation of a network of cooperatives in Recife. The software was designed with a large button that allowed turning off data collection, if the collector chooses so. Nevertheless, this option was rarely used by the collectors. It is not clear, however, to what extent the cooperatives understood the value as well as potential drawbacks of data. One group sent monthly reports about the collected material to the municipality, but did not keep any copies of this information in the cooperative.

Interface issues

In general, the subjects in Recife had little difficulty working with the android applications. However, their feedback highlighted a number of issues. One issue was presented by the multiple steps necessary to input the data, starting from switching on the phone, unlocking the screen, and launching the application. In response, we changed the interface to a more simplified version during the workshop. Since some collectors were not able to read, we labeled interactive elements to pictograms rather than text. Most collectors were navigated the software almost without effort, and one interview partner stated that his colleagues who cannot read were more successful using our prototype and navigating its visual interface than the more literate collectors.

Other issues arouse during tests in the field. Reading from the screen in daylight was a challenge, as was the use of touchscreens in a hot, humid, and dirty environment.

Using a visual interface by memorizing the necessary steps to accomplish a specific task is one issue, a deeper conceptual understanding of the underlying technology another. In our work with COOPAMARE, we saw that the collectors were surprisingly capable of interpreting plain GPS traces without further contextual clues such as photos of locations. Understanding the concept of real-time data was more challenging. In the Recife workshop some participants were surprised when a photo taken with one device instantaneously appeared on a different device in a different part of the room.

Conclusion

Brazil's approach to formalization of waste scavenging can be described as decisively market-oriented. Governments do rarely directly fund cooperatives; instead, they act as supervisors, mediators, and facilitators for business partnerships, which provide material support for cooperatives. The goal of formalization is to make cooperatives able to act as independent companies and take on collection contracts, in line with what Scheinberg calls the commodities model of formalization.

This study created a multi-faceted picture of waste management at the boundary between formal and informal. The value chain, linking scavengers, waste haulers, intermediaries, the recycling industry with manufacturing and retail is a text-book example of the tight intertwinedness of formal and informal actors described by the structuralist perspective on informality. We also found many examples that strongly support the voluntarist perspective, such as the case of independent informal collectors who prefer not to join cooperatives.

We found that all cooperatives report to the local government on a regular basis. However, the cooperatives treat the monthly reports to the city as a necessary aspect of formalization without always understanding its purpose. For cooperatives, the most tangible benefit of data collection and reporting comes from the interaction with companies: by gaining access to new contracts and increasing revenue. The tendency of waste systems to become more data driven will intensify in the course of the NPSW implementation.

To what extent the new law will reward good data collection practices by making better prices possible, remains to be seen. Will these be better alternatives to selling to intermediaries, where no accountability is necessary, but also prices and profits are lower? As of now, the governments are not very active in enforcing data reporting from cooperatives.

Technology in low-income environments is often discussed in terms of the digital divide: economic and educational inequality as an access barrier to technology. While these are important questions, there are other more important parameters, which are often overlooked. The trust issue arising from the effect through technology, as encountered in our work with COOPAMARE, is one such example. The use of digital technology by users who lack basic education and literacy is a tricky problem that deserves more attention; and our observations in this regard are only anecdotal. Nevertheless, it should not be automatically assumed that illiteracy is a prohibitive limit to using technology.

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Appendix

Table 18 Interview subjects and local experts

Interview Partners Cooperatives		Local Experts
Rede CataSampa **São Paulo, SP**	João Ruschel	Dr. Lúcia Helena Xavier (FASPE, Recife) Prof. Dr. Maria Cecilia Loschiavo dos Santos (USP)
CRUMA **Poa, SP**	Roberto Golfhino	Prof. Dr. Flavia Scabin (FGV) Prof. Dr. Tereza Cristina Carvalho (CEMPRE)
Coop-Reciclavel **Guarulhos, SP**	Cristiano	Mateus Mendoza (Giral) Diogo Vallim (Giral)
COOPAMARE **São Paulo, SP**	Maria Dulcinea Laerte Paz Manuel Soares Walison da Silva Francisco da Silva Elisonete Ferreira Da Conçeicão	João Ruschel (CataSampa) Laura Fostinone Ana Bonomi Rafael Galvão
COOCARES **Abreu e Lima, PE**	Lindaci Gonçalves	**Team MIT**
COOREPLAST **Abreu e Lima, PE**	Roberto Antonio Gonçalves Vânia Maria da Silva	Dietmar Offenhuber David Lee
Pro-Recife **Recife, PE**	Roberta da Santana Pessoa Maria dos Prazeres Santana José Cardoso	Libby McDonald
Nossa Vida **Recife, PE**	Pedro Lima Alcantara Adeilda de Lima André Carlos da Silva Cardoso José de Iterlao Nefo	
City of Olinda **Olinda, PE**	Tereza Cristina Angelo da Silva	
Environmental Ministry of the State of Pernambuco **Recife, PE**	Ana Gama	

Infrastructure Legibility – a comparative analysis of open311-based citizen feedback systems

Preface

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Abstract

During the past decade, most large US cities have implemented non-emergency incident reporting systems via telephone helplines, websites, and more recently, mobile applications. Using data from systems operating in the larger Boston area, and spatial and grounded theory analysis of submitted reports, this paper investigates the role of design in shaping the interaction between the citizens and the city. It investigates the following questions: Which assumptions about the users are embedded in design of existing feedback systems? What motivates users to participate, and how do the systems' design choices correspond with these motivations? By what mechanisms do these systems facilitate and constrain the interaction between citizen and city?

Introduction

The recent history of citizen feedback systems is a tale of growing ambition. In the past decade, most large US cities have implemented non-emergency incident reporting systems via telephone helplines, websites, and recently mobile applications. During that time, 311 systems, named after the three-digit US telephone short-code reserved for that purpose, have evolved from service hotlines to public accountability instruments, data source for urban maintenance and tools for civic engagement. The trajectory of these recent developments raises the question: to what extent can and should citizens be involved in the processes urban maintenance? Numerous tensions exist: between the voluntary nature of involvement and the reliability and homogeneity expected from urban services; between the private motivations of participants and their perception of a public good; between engagement and accountability.

By examining how the design factors of existing systems correspond with the practices and stated motivations of the users, this essay investigates design principles for participatory infrastructure systems, with special focus on questions of accountability and the capacity of the interface to negotiate the interests of citizens and the service provider.

Problem and Research Questions

Despite a shared concern for well-managed urban services, the interests of citizens and city are not identical. A feedback system designed according to the expectations of the citizens will therefore be different from a system reflecting the needs of the city. These goals and interests are ultimately negotiated through the interface, which regulates the possible forms of interaction and determines the representation of the system.

The goal of this paper twofold: first, to identify and articulate the role of design in facilitating or constraining the interaction between the citizens and the city; second, how these design choices correspond with the motivations of the users of these systems. I hypothesize that the degree to which individuals engage in infrastructure governance depends on the legibility of the infrastructural system - the extent to which the interface represents the system's structure, processes, and social dimensions. Infrastructure legibility depends on design choices, since the designers of citizen feedback systems have to make basic assumptions about their users, their motivations and expectations, and whether users are driven by a personal grievance, or by the concern for the public good. The three main research questions are consequently:

RQ1 – design: Which assumptions about the users are embedded in the decisions guiding the design of online 311 platforms? How are these assumptions translated into design features?

RQ2 – motivations: What motivates users to participate, and how do the system's design features correspond with these motivations? For example, to what extent are contributors motivated by self-interest, to what extent by concern for the public good?

RQ3 – transformative effects: By what mechanisms and design principles do existing systems facilitate and constrain the interaction between citizen and city?

A short history of 311-citizen feedback systems in the US

In February of 1997, the US Federal Communications Commission designated a new nationwide abbreviated number, 311, for quick access to non-emergency police and government services. The reason for this decision was a steep increase in emergency calls, which was attributed to the wide-spread adoption of cell-phones and created a burden for 911 call centers (Hester 1997; Flynn 2001; FCC 1997). In the same year, the City of Chicago started to plan a new community response system, replacing an outdated mainframe system. The new 311 System assumed operation in January 1999 (City of Chicago 2013); small-scale pilot programs were previously launched in the cities of San Jose and San Diego (Department of General Services 2000).

In 2002, following these early examples, New York City's Major Bloomberg announced plans for installing a new citywide 311-phone system for handling non-emergency calls, as his first major policy initiative.. Until then, 12 different call centers were operating in the various departments of city, often with a significant overlap in their competences, resulting in requests frequently being sent back and forth between different departments. At this point, it became increasingly clear that merging the different call centers into one new system would likely not reduce the number of 911 calls, as previous studies on 311 pilot projects in San Diego and San Jose had shown (Department of General Services 2000). Instead, the focus shifted to the potential benefit of improving and simplifying access to communal services for the city's diverse population (Cardwell 2002). New Yorks new 311 call-center, operating under the Office of Operations, was established in 2001 and staffed by 300 phone operators who receive calls and parse requests into the service categories provided by a Service Management System, which then generates tasks for the appropriate department. A team of 12 analysts and engineers continuously revised the protocols and database structures designed for parsing and routing the incoming requests. Tracking how quickly things were handled in the city and evaluating urban performance was an initial goal for using the 311 records. The aggregated data from citizen requests turned in many cases out to be more reliable than official data collected by service inspectors (Van Ryzin, Immerwahr, and Altman 2008). Furthermore, the full value of the data for urban maintenance operations was not anticipated. Many issues surfaced in the call data that would otherwise have gone unreported by conventional mechanisms, such as reports about dead animals and other public health issues. Besides using the call data as a basis for monthly service performance reports, the City of Chicago has used the volume of 311 calls also for tracking bedbug infestations (Gabler 2010). The data set was also instrumental in tracing environmental emissions their source facilities based on reports from people reporting or air emissions causing unfamiliar odors (Johnson 2010).

Early online systems

While the possibility of using the web and email for service requests were absent in the first deployment of New York City's 311 System, these ideas started to materialize in 2005 through a bottom-up initiative. Public advocate Andrew Rasiej launched a website for mapping the city's potholes, creating public pressure on the city for having them fixed (Shulman 2005). Driven by the broad adaptation of smart-phones and location-based technologies, many comparable services followed. Some of them were bottom-up initiatives focusing on local government transparency, such as the platform "SeeClickFix", developed by an U.S. start-up in 2008, following the earlier example of the "FixMyStreet" website in the U.K. Other systems were initiated by cities, such as New York's "311Online", active since 2009 was initiated and promoted by the city itself; Boston's "Citizen Connect" initiative, operational since 2010 and initiated by Boston's "New Urban Mechanics" group inside city hall, and implemented by the company "Connected Bits".

The open311 standard

The rapidly increasing number of cities and communities developing their own version of an incident reporting systems from scratch made it necessary to think about improving interoperability. In 2009, a new standard for unifying incident reporting systems under the name "Open311," developed in the course of the first "Apps for Democracy Contest" ("Apps for Democracy" 2013). The Open311 protocol is now supported by most 311 systems across the US. The nature of open standards such as open311 makes it possible to use a wide range of different clients, platforms and interfaces, while having the advantage of a standardized, machine-readable data stream that allows citizens and companies to build own applications on top of the existing data infrastructure. Online 311 systems fall within the domain of Volunteered

Geographic Information (VGI) systems, including community-driven mapping projects such as OpenStreetMap ("OpenStreetMap" 2013) or disaster relief and accountability focused initiatives such as Ushahidi (Goodchild 2007).

The accountability dimension of citizen feedback systems

Citizen feedback systems are also accountability instruments. They build on the concept of Social Accountability, describing mechanisms that rely on civic engagement for keeping power-holders accountable (Malena, Forster, and Singh 2004).

New York's Mayor Bloomberg, the driving force behind the implementation of the 311-system, saw it as a way to improve the interaction between different city departments. An interview partner, who worked as an analyst during the early days of the system recalled in an interview how the mayor was known for frequently and anonymously calling in from different parts of the city, reporting issues to probe the responsiveness and quality of the service.

From a social accountability perspective, 311 systems imply a two-way contract between the government and the citizens. The city commits to responding to citizen requests in a timely manner and offers a mechanism for the citizens to track requests. In return, the citizens contribute data that again is made publicly accessible – as mandated by the Freedom of Information Act (FOIA).

Since this kind of public visibility is not without drawbacks for the city, especially when it comes to issues of infrastructure management, why would a city choose a pro-active role in promoting social accountability? One answer is that citizens who feel a lack of accountability would eventually create such a system anyway. Such "rude" forms of accountability (Hossain 2010), operating by 'naming and shaming' might in the long run be more harmful for a local government compared to a proactive solution that emphasizes the common goals both citizens and the government share.

It should not be forgotten that income inequalities are closely connected to a community's inclination to request accountability. Studies of citizen grievance systems in India have shown that residents living in the most deprived areas are often not the ones who complain the most; instead, complaints are concentrated in the better-serviced middle-class areas. The authors observe that grievance systems often capture the 'wants', rather than the 'needs' (Martínez, Pfeffer, and van Dijk 2009; Verplanke et al. 2010, 194).

Infrastructure legibility

Participatory civic technologies are frequently categorized into dichotomy such as top-down versus bottom up – whether these technologies originated from government initiatives or were built by citizens. Such a categorization may seem appropriate, as both sides represent different interests. However, in the case of citizen feedback systems, we see that different origins do not necessarily result in fundamentally different systems - they share many similarities in terms of design, organization, and operation.

This essay uses a different approach and focuses on the processes and interactions that take place at the system boundaries between user and provider, citizen and city. This interface-centric perspective draws from actor-oriented research approaches, including Susan Leigh Star's anthropology of infrastructure, which conceptualizes infrastructure as a relationship between technical systems and human practices (Star 1999), and, to a limited extent, Actor-Network Theory, whose concept of non-human agency is particularly relevant for software and technical artifacts (Callon and Latour 1981; Latour 2005).

To address the central question of how the design of citizen feedback systems mediates between citizen and infrastructure providers, I introduce the construct of 'infrastructure legibility' as a quality afforded by citizen feedback systems. Infrastructure legibility means the degree to which the features of an infrastructural system can be recognized by its users or governors with regard to (1) the system's structure and its processes, (2) the system's governance, and (3) the presence of users in the system.

I adapt the concept of legibility from the classic work by the urbanist Kevin Lynch, who hypothesized that the perceived quality of an urban environment is related to the degree to which its inhabitants are able to 'read' its structure (Lynch 1960, 2). The Lynchean concept has since been applied in Human-Computer Interaction (HCI) to address wayfinding issues in informational space (Morville 2005). Equally relevant for this study is James D. Scott's conceptualization of legibility as a central issue of governance that allows the modern state to exert its power (Scott 1999).

With regard to citizen feedback systems, one aspect of infrastructure legibility concerns the representation of the mediating technology itself. Citizen feedback apps are deeply entangled with their physical surroundings, the practices of their users, and the urban infrastructures they address. Under the terms Seamless and Seamful Design, the ubiquitous computing literature offers two different design approaches for how such integration can take shape. Seamless Design follows the idea of the invisible interface and hides all technical complexities from the user (Weiser 1994). Seamful Design represents the opposite approach, uncovering the discontinuities, boundaries, and internal processes of a system (Chalmers and Galani 2004; MacColl et al. 2002). While Seamless Design emphasizes unobtrusiveness, a 'seamful' system emphasizes legibility, inviting customization and scrutiny.

A second aspect encompassed by infrastructure legibility is the way other participants, citizens or city employees, are represented. The concept of Social Presence describes the degree to which a communication medium is capable of conveying the salience of a communication partner including all verbal, non-verbal, and contextual cues. Users of a specific communication medium are aware of the degree of Social Presence it allows, and consequently adapt the way how they use the medium (Short, Williams, and Christie 1976). For the sole purpose of submitting incident reports, an anonymous system would be sufficient, especially as privacy remains a concern. However, strict anonymity may not always be desirable. The system governor might seek protection against vandalism and block repeated offenders. More importantly, also the submitter might prefer to be more present in the system and be acknowledged as a contributor. To negotiate the need for privacy and the desire for social presence, the I.B.M. researchers Wendy Kellogg and Thomas Ericsson introduced the concept of Social Translucence, using the metaphor of a frosted glass door that hides the identity of people behind it, but conveys an idea about the activity in the room (Erickson and Kellogg 2000).

The specific forms of representation chosen for participatory systems are an effective method for what Steven Woolgar terms the configuration of the user (1991). The design of the interface, the inclusion of certain elements and the omission of others shape the likely future actions of the user into a direction preferred by the designer. How this configuration happens in the case of citizen reporting applications is the subject of a study by Matthew Wilson. In his analysis of a controlled geocoding experiment, Wilson describes how design decisions such as the choice of incident categories, help to direct and configure the cartographic gaze of the user (Wilson 2011).

Participant motivations

From the perspective of the user, a report may be driven by a personal grievance or by a desire to improve the city or both. When it comes to the question how broad participation can be encouraged, the issue becomes more complicated. Traditional volunteer organizations such as the Appalachian Trail Conservancy, maintaining 2000 miles of hiking trails through the work of volunteers, rely on the creation of Social Capital as an incentive for participation (Appalachian Trail Conservancy 2012; Putnam 2001). In online communities, social relationships tend to be more context-oriented, and Intellectual Capital, the generation of knowledge and sharing of information, becomes an important motivational factor (Rafaeli and Ariel 2008).

Citizen feedback apps operate in both spaces, using online coordination to address issues that affect the participants in physical space. However, they lack many incentives for participation mobilized by volunteer organizations and online communities: they provide few opportunities for social interaction, for learning, personal growth, or gaining prestige. Coleman et al. investigated the motivations of users who volunteer geographic information to dedicated platforms (D. J. Coleman, Georgiadou, and Labonte 2009)

The authors propose a framework that characterizes the user motivations in a two dimensional matrix, linking the level of user expertise (neophytes, interested, expert amateurs, professionals, or expert authorities) with the nature of information platforms (commercial products, social communities or governmental platforms). In a following study, Coleman linked user motivations to certain design characteristics of the used technologies (D. Coleman, Sabone, and Nkhwanana 2010). Looking beyond mere participation, Gordon and Baldwin emphasize the potential of citizen feedback systems for cultivating reflection on civic habits (Gordon and Baldwin-Philippi 2013).

Methods & Data sources

The empirical analysis focuses on platforms used in the metropolitan region of Boston, which offers a wide variety of active citizen feedback systems operated by the different municipalities in the region. This includes the city of Cambridge, using their own iReport system; the city of Boston, which also operates its own system under the name Citizens Connect and, more recently, also officially supports the generic platform SeeClickFix. The city of Brookline uses a system under the name BrookONline, identical to Citizens Connect in terms of its functionality (for geographical reference, see Figure 30). This co-existence of various different systems in a continuous metropolitan area makes the Boston region an ideal place for this study. The city of Boston itself officially supports two systems of a very different design. As both interfaces feed into the same central CRM in the city of Boston, the response of the city can be assumed being equal and the effects of design can be expected to be more salient.

The three research questions will be answered as follows:

- The first question concerning design factors of existing systems will be addressed using comparative analysis of existing systems (Table 19).
- The second question concerning the motivations of volunteers will be measured using textual analysis of the language submitted in incident reports based on the Grounded Theory approach (Glaser and Strauss 1967).
- The third question concerning transformative effects will combine results from the textual analysis with the comparative analysis of design factors with respect to specific aspects of the interaction.

Content analysis of submitted reports

From the 30278 reports submitted via CCN, a random sample of 1172 reports was drawn, while the whole SCF data set concerning the city of Boston was used, consisting of 695 issues and 1780 reactions. All fields of the incident report were considered in the analysis, including a photo of the incident, the geographic location, a free-form textual description of the incident, and, in the case of CCN, the incident category, and in the case of SCF, the short, user-defined title of the incident. The information entered into the description field is optional, yet used by most reporters. The length of a description typically rages from a single line to a few sentences, describing the nature of the incident; often explaining why the incident is considered important and how the city should respond. The description is often contextual, and requires the photo, the location, or the specified category for understanding the nature of the request. The descriptions offer a wealth of explicit and implicit information, however, in an unstructured format. To extract this information for the purposes of analysis an open coding approach was used to capture the implicit information into more structured categories derived from the data.

At first glance, the descriptions show certain characteristics. They differ in tone – some use highly critical or accusatory language, while others are neutral (see Table 22b). They may express a certain concern – the safety of others potentially affected by the incident, the aesthetic appearance of the city, or the behavior of other people. They also differ in terms of the reaction they expect from the city. Often the intent of the reporter remains ambiguous, or multiple issues are addressed simultaneously. The analysis of the reports started from the most salient features, for example, by identifying reports that report other people, or reports that explicitly express safety concerns. In the following iterations, the list of identified features was refined and expanded. In a last step, this broad list of features was combined into a smaller set of categories, using a shared definition for each category. For example, a report with a very critical tone was defined to contain explicit expressions of anger, dissatisfaction, or accusations, while a report was considered critical, if it emphasizes the urgency of the reported issue. Some of the salient characteristics were defined as properties rather than categories to allow for combinations of more than one characteristic where necessary.

Since about half of the CCN reports were submitted under the unspecific "other" category offered by the system and the SCF reports required no categories at all, the first necessary step was to identify the nature of the reported incident. For this purpose, the initial categories from CCN were used, and then gradually expanded. An important distinction emerged for example between reports that were addressing infrastructure repairs, such as replacing a broken lamp, and infrastructure improvements, such as requests for an additional park bench or trash bin. The operational definitions of the individual categories and properties can be found in Table 26 in the appendix.

Table 19 Comparison of incident report systems

#	System	In operation since	Initiated by	Geographic Area
1	Standard Open311 Specification	Jun 2009	Consortium / public sector	Location independent
2	SeeClickFix	Sep 2008	Start-up	Location independent
3	FixMyStreet	Feb 2007	Non-profit	UK
4	Cambridge iReport	Dec 2011	Public sector	Cambridge, MA
5	SpotReporters - Citizens Connect / BrookONline	Sep 2009 / Sep 2010	Public sector	Boston, MA / Brookline, MA
6	NYC 311 online	Mar 2003	Public sector	New York City
7	City Sourced	Sep 2009	Start-up	Location independent
8	Ushahidi	Jan 2008	Start-up / non-profit	Location independent

Compared Systems and data sources

In the comparative analysis of the design factors, the Boston platforms are contextualized within a range of comparable web and smartphone-based systems, both location-dependent and independent (Table 1). Most of these systems allow submitting an incident report either via a web site or a mobile application. An incident report typically includes a photo of the incident, a geographic location, a free-form textual description of the incident, and an incident category selection. Some of the systems are specifically developed for a single city, such as New York City or Cambridge. Other systems, such as SeeClickFix and CitySourced, are location independent, but usually not supported in every city to the same extent. Also included in the comparison is the standard specification for incident reports, Open311, which has become the basis for many municipal systems as well as generic tools.

Spatial Characteristics of the Boston dataset

In most cities, reports submitted via Open311-type mobile applications still constitute the minority of service requests. During the years 2011 and 2012, the city of Boston has received a total number of 242354 service requests via different channels such as telephone calls, face-to-face meetings, or email. Among these requests, only 30278 (or 12.5%) were sent from Boston's Citizens Connect app.

Digital and analog requests are not evenly distributed in space. Figure 1 presents an aggregated map of reported incident locations showing the ratio between the number of reports submitted via analog (phone) and digital channels (website, email, mobile app). Red areas indicate that the large majority of reports were submitted via analog means. Blue areas indicate more digital requests, and concentrate in public spaces with high pedestrian activity, parks, and beaches. The map shows a pronounced 'digital divide' in citizen requests: the southern, least affluent neighborhoods of Boston - Roxbury, Mattapan, South Dorchester – show the lowest likelihood to use digital feedback channels.

A second perspective is provided by the origin of the reporters. About 37% of the requests via phone-hotline included a zip code of the reporter's residential home; unfortunately, this was only the case for 3% of the smart-phone application requests. Among those request with a known reporter zip code, the reported issue was in the large majority of cases located in the same zip code where the reporter lived (Table 20). Acknowledging the limitation of the low spatial resolution, this supports the assumption that people tend to report issues in their own neighborhood (the location of the work place is unfortunately not captured in the data set).

Table 20 Boston service requests: reported location versus home location of the reporter, by communication channel (courtesy Curt Savoie, City of Boston).

Channel	Reporter zip code known		Incident not in reporter zip		Incident in reporter zip	
Citizens Connect App	1034	3.1%	176	25.7%	510	74.3%
Constituent Call	55795	37.3%	6436	15.1%	36245	84.9%
E-mail In	126	77.8%	88	87.1%	13	12.9%
Mail In	6	66.7%	3	50.0%	3	50.0%
Self Service via website	9880	26.0%	1360	15.7%	7294	84.3%
Other via website	150	11.5%	25	20.2%	99	79.8%

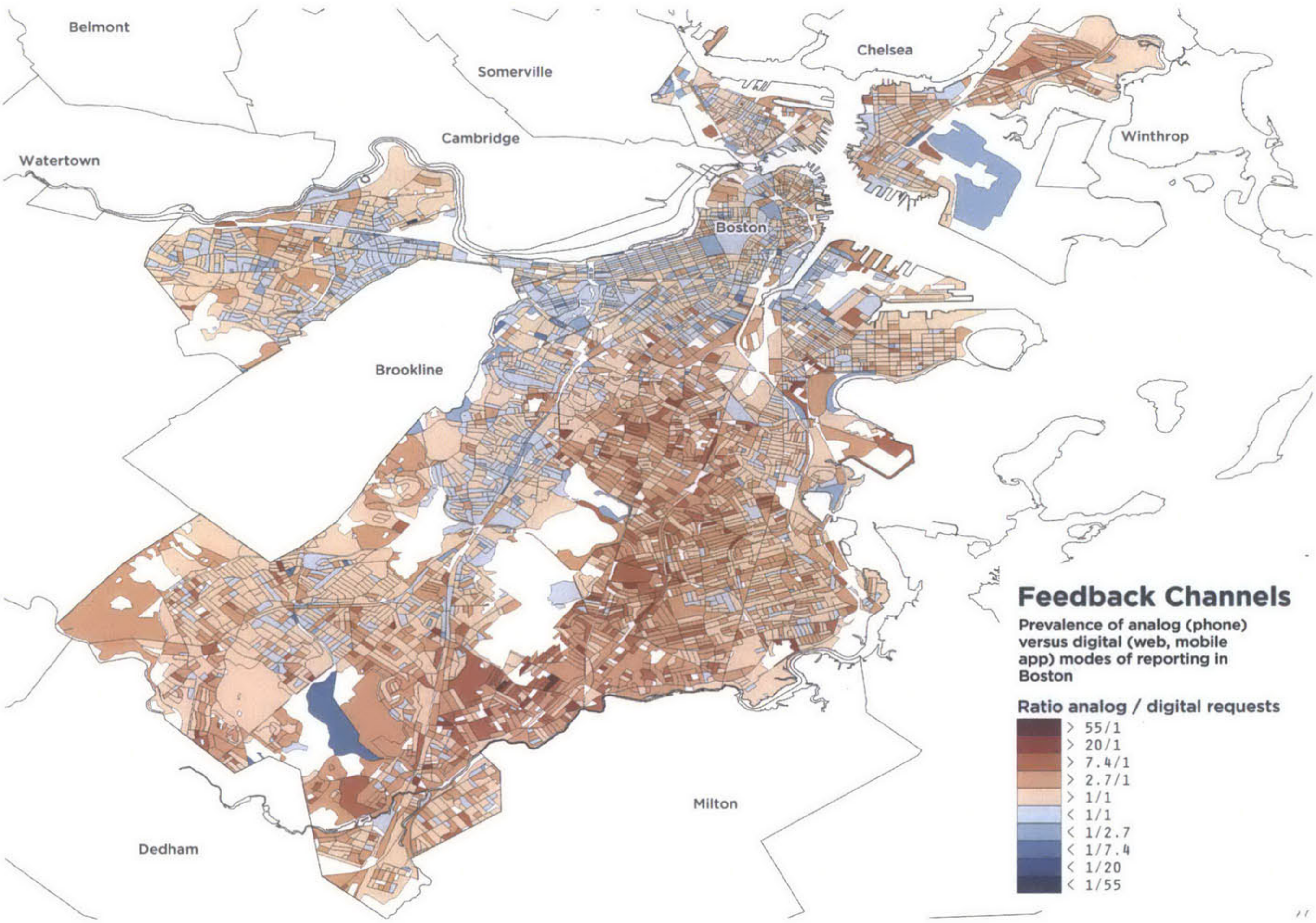

Figure 30 Analog versus Digital service requests to the city of Boston. Blue areas have more digital reports (mobile apps, web, email), red areas more analog (Phone calls). Data source: Boston CRM data, all 242354 requests from 2011 (data-set courtesy Curt Savoie, City of Boston).

RQ1: Design factors of the compared 311 systems

Table 21 provides an overview over the basic design features of the two compared systems. While most systems involve both a web component as well as a mobile app, some platforms place more emphasis on the website (2,3,6,7,8), while others place more weight on the mobile component (4,5).

As of this writing, most of the compared systems publicize the submitted reports along with a textual response of the service provider (all except 4 and 8). This includes a status indicating whether the issue has been resolved, often accompanied by an explanation of what the provider has done to resolve the issue. With the exception of Cambridge's iReport, each of these systems also provides some form of a contextual display showing nearby reports, either as a map or as a list.

The public display of reports is limited in different ways. Compared to websites, mobile apps are constrained in terms of information and complexity that can be displayed, but offer the advantage of using the user location for filtering relevant data. Web sites allow for more complexity. In the case of Boston, the website offers three levels of representation – aggregated in monthly performance indicators, mapped in a web-GIS application, and listed as a real-time feed of incoming reports (City of Boston 2013; City of New York 2013). However, the actual incident descriptions are only accessible via the citizens connect live-feed, effectively limiting the visibility of offensive reports. In the case of New York, they are entirely absent. This decision may help prevent vandalism through submission of unrelated and offensive text and images, but it also limits the visibility of notorious complainers, who reinforce each other in their attitude against the city. The ephemeral nature of a real-time twitter feed paradoxically renders the system more opaque by making it harder to find an individual report in the stream of constantly updated information. Consequently, vandalism and offensive comments are hardly ever submitted according to the CitizensConnect operators in Boston City Hall. SeeClickFix has chosen a different strategy for displaying reports. Unlike Boston and New York's proprietary systems, SeeClickFix places its main emphasis on the public discussion of the submitted reports in a highly visible public forum. Its interface does not stop at a passive display: users can proactively sign up public officials using their public email addresses to receive the complete feed of issues and comments concerning a specified area. The platform, however, does not include functions for analysis and visualization of historic data.

Many cities offer aggregated data sets of the submitted reports and key performance indicators of various urban services. However, none of the compared feedback systems show the real-time activity of the public works department beyond the response to the submitted reports, for example by showing the locations where the city's workforce is currently active. Such a feature would allows seeing an otherwise isolated incident in context, which could increase the acceptance and engagement on the side of the citizen.

The legibility of the reporting system itself is captured in the concepts of seamful versus seamless design (Table 21). In the context of citizen feedback systems, a seamful system may offer open access to internal protocols and raw data on a programmatic level, while a seamless system limits access to the functions of the end user interface. Cambridge iReport is an example of a seamless system: it does not allow any customization nor provide feedback that offers clues to what happens when a report is sent; user requests are limited to a fixed set of service categories. The Open311 standard, on the other hand, is inherently seamful. By including internal service codes and information about referrals to other agencies, Open311 systems represent the organizational structures, boundaries, and seams between the different departments of the city government. Via its exposure of technical processes, Open311 systems establish also a legibility of infrastructure governance.

The representation of the human side of infrastructural systems is investigated through the concept of Social Presence (Table 21). The open311 standard in its current form (V2.0) represents the interaction of users and governors only to a limited degree. Both user requests and the response from the provider are treated as anonymous, since the standard does not provide for any kind of personalization. As a consequence, open311-based client apps allow for little social presence. However, there are workarounds: many open311 based systems, including Citizens Connect and BrookONline forward their reports via the Twitter platform, which allows for a more personalized interaction. The representation of users is more prominent in the web-oriented systems (2,3, and 7 in Table 1). Following established social media design patterns, the users of SeeClickFix and CitySourced can create personal profile pages. Cities and city officials are both represented in a similar way. Interestingly, SeeClickFix does not make a principal distinction between citizens and public officials, who often register and contribute as regular users.

A minimalist vs. a social approach

Concluding from the previous observations, the design choices of the compared applications follows two different philosophies, which could be called the minimalist and the social approach. The first approach focuses entirely on one-to-one interaction between the individual and the city. Its interface is minimalistic, aimed at streamlining the communication of the citizen reporter with the public works department. The range of possible interactions is therefore deliberately constrained; the choice of service categories fixed. This approach has been chosen by the developers of NYC 311online, the iReport system recently launched in Cambridge, and to some extent also for the Spotreporter systems Citizens Connect and BrookONline.

The second approach focuses on a more social, many-to-many interaction among citizens and service providers, aims at establishing a community of practice around the activity of incident reporting. Consequently, platform such as SeeClickFix feature many elements familiar from other social media platforms. Citizens and public officials alike are represented via user profiles; users have the possibility to rate and comment on existing issues, their activity feeds into a simple reputation system.

While a minimalist design succeeds in simplifying the direct interaction between citizen and city, there are situations where a many-to-many conversation would be beneficial. The social functions of SeeClickFix were for example used to coordinate snow shoveling among neighbors during a snowstorm (Snowcrew 2012).

Reasons for choosing the minimalist approach

Often, the design of feedback systems is constrained by the historical factors. Existing systems involve complex database structures that are generally difficult and expensive to change. However, a minimalist design also offers advantages. A well-defined set of possible interactions can be more efficiently managed by a public works department: a single report about a broken streetlight can be immediately added to the respective task queue; a broad discussion around the pros and cons of adding a crosswalk is less actionable for the service provider. A minimalistic interface might also be more accessible for a broad population compared to the more complex social media approach. In an interview with the author, an IBM researcher challenged the philosophy behind the latter approach as the "the web-way of thinking," which does not translate well into urban space, especially keeping in mind barriers such as the tedious text-entry on the keyboard of a smartphone. In his view, citizens do not necessarily appreciate social features, when their main interest is that their complaints are heard and acted upon. From an accessibility standpoint, the design patterns of social media might be attractive for tech-savvy users, but at the same time, they represent an obstacle for less technology-literate citizens.

Table 21 Design factors of the compared systems

System #	1	2	3	4	5	6	7	8
	Open311	SeeClickFix	FixMyStreet	Cambridge iReport	Spot Reporters	NYC 311 online	City Sourced	Ushahidi
Main platform	NA	Web / mobile	Web	Mobile	Mobile	Web	Web	Web
Paradigm	NA	Social	Social	minimalist	minimalist	minimalist	Social	Social
System legibility								
Reports publicly visible?	Via API	Dedicated site	Dedicated site	No	Dedicated site	Yes	Yes	Dedicated site
Public response from provider?	Yes	Yes	Yes	No	Yes	No	Yes	Yes
Seamful vs. seamless								
Raw Data Access	Open311	Free API / Open311	Commerci al API	No	Open311	Open311 (v1.0)	Free API / Open311	Free API / Open311
Tools for data analytics	No	No	No	No	Via data portal	Via data portal	No	Yes
Social presence								
Anonymous use possible?	NA	Yes (guest)	Yes (guest)	Yes	Yes	Yes	No	Yes
Other users visible?	No	Yes (opt-in)	Yes (opt-in)	No	No	No	Yes (opt-in)	No
Can users respond to other reports?	No	Yes - vote, comment	Yes - comment	No	No	No	Yes - vote, comment	Yes - verify, vote
Reward system	No	Top users, points	No	No	No	No	Yes / voting	No

RQ2: Stated Motivations of users

Ultimately, the designers of feedback systems have to consider whether the citizens would appreciate a complex social interface, when they want is their grievance being addressed by the city. While infrastructure services are considered a public good, the individual citizen might treat the service as a private good. Therefore, one could argue that the minimalist approach renders the urban service as a private good, and involves an implicit assumption of a user pursuing his or her self-interest. The social approach highlights the role of infrastructure as a public good, and assumes users who are interested in civic issues.

The following section will concentrate mainly on two systems operating in the Boston area, Citizens Connect (CCN) and SeeClickFix (SCF), which were selected for several reasons. Both systems provide access to the report descriptions, are technically comparable, and their reports are answered by the same city department. More importantly, each respective system is an almost pure embodiment of the minimalist and the social paradigm. Citizens Connect is a government-driven system with an emphasis on service delivery; the interaction can be characterized as one-to-one and anonymous, with an emphasis on mobile usage. SeeClickFix is a privately driven effort with an emphasis on social accountability. In this system, the interaction can be characterized as many-to-many and less anonymous. While SCF offers a mobile application, the website is still the central element of the platform.

From the 30278 reports submitted via CCN, a random sample of 1172 reports was drawn, while the whole SCF data set concerning the city of Boston was used, consisting of 695 issues and 1780 reactions.

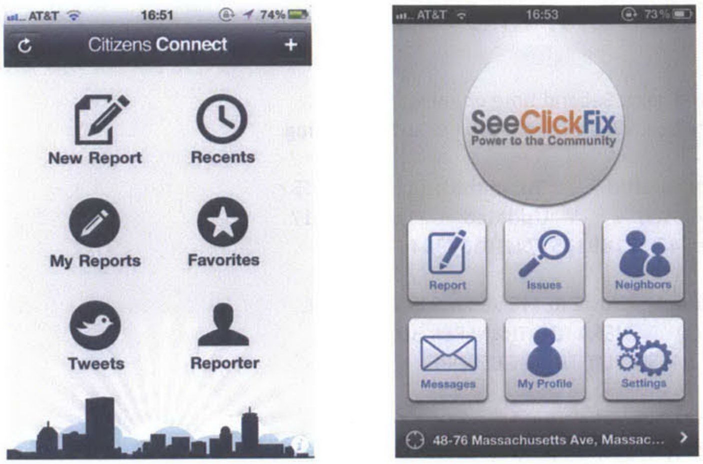

Figure 31 Screenshots of the Citizens Connect (CCN) and SeeClickFix (SCF) Smartphone app interfaces – the latter affords additional social presence by allowing to explore virtual neighbors.

Table 22 Citizens Connect: composition of the sample by submitted Service Categories. Most reports are submitted under the unspecific "other" category provided by the system.

Service category	N	%
Other	573	49%
Graffiti	201	17%
Pothole	175	15%
Streetlight	122	10%
Sidewalk Patch	41	3%
Damaged Sign	25	2%
Unshoveled Sidewalk	26	2%
Roadway Plowing/Sanding	9	1%
Total	**1172**	**100%**

Submitted text: Second time opening this issue. On utility box. Was closed last week without being fixed.
Category: Graffiti **Submitted:** 11/1/10 8:05
Status: Closed **Updated:** 11/4/10 11:17
Location: 42.32189175 -71.10108364

Service Reply: CAN'T REMOVE THIS IS A PRIVATE ELECTRICAL GENERATOR TRANSFER BOX...I BELIEVE I ALSO PUT THIS IN BEFORE.

tone: critical, **motivation:** aesthetic concern, **incident type**: graffiti, **properties:** follow-up, accountability, custom reply

Figure 32 An example of a submitted Citizens Connect Report with associated Metadata, the reply of the service provider, and the categorization in the content analysis.

Table 23a Comparison Citizens Connect (CCN) vs. SeeClickFix (SCF): Types of incidents submitted (left), Motivations expressed (right)

	CCN		SCF		
Incident type	**N**	**%**	**N**	**%**	**difference**
Animals	16	1%	7	1%	
Graffiti	210	18%	16	2%	
Ice	37	3%	3	0%	
Infrastructure improvement	39	3%	92	13%	
Infrastructure repair	493	42%	466	67%	
Other violation	40	3%	13	2%	
Plants	42	4%	11	2%	
Social issues	7	1%	10	1%	
Test / unknown	13	1%	8	1%	
Traffic	64	5%	39	6%	
Trash / litter	211	18%	29	4%	
Total	**1172**	**100%**	**694**	**100%**	

	CCN		SCF		
Motivations expressed	**N**	**%**	**N**	**%**	**difference**
Aesthetic concerns	174	15%	33	5%	
Bad personal experience	15	1%	32	5%	
Concerns with disrepair	305	26%	249	36%	
Dissatisfied with the city service	38	3%	12	2%	
Ideas / discussion civic issues	39	3%	76	11%	
Other people's behavior	108	9%	47	7%	
None specified	345	29%	118	17%	
Public health / sanitation	37	3%	11	2%	
Safety concerns	111	9%	116	17%	
Total	**1172**	**100%**	**694**	**100%**	

Table 23b Comparison Citizens Connect (CCN) vs. SeeClickFix (SCF): Tone of report (left), selected non-exclusive Properties (right)

	CCN		SCF		
Tone of report	**N**	**%**	**N**	**%**	**difference**
Very critical	38	3%	19	3%	
Critical	205	17%	204	29%	
Friendly	54	5%	30	4%	
Neutral	577	49%	317	46%	
No text	234	20%	104	15%	
Plea	64	5%	20	3%	
Total	**1172**	**100%**	**694**	**100%**	

	CCN		SCF		
Properties (non exclusive)	**N**	**%**	**N**	**%**	**difference**
Demanding Accoutability	60	5%	30	4%	
Complaint in strong language	37	3%	21	3%	
Reporting other people	118	10%	26	4%	
Concern for safety	143	12%	140	20%	
Suggesting Improvements	53	5%	81	12%	

Types of Incidents

Table 22 breaks down the Citizens Connect reports analyzed in the random sample by the currently seven different service categories provided by the system. Since about half of the CCN reports were submitted in the open "Other" category and the SCF reports required no categories at all, further analysis was needed to identify the nature of the reported incident (Table 23, top left). In both systems, but especially in SCF, the largest group of the reports concern infrastructure repair in the broadest sense, including street and sidewalk surfaces, lights, signals and urban furniture. Incident reports concerning trash / litter, as well as graffiti comprise each about a fifth of the CCN reports. In comparison, these topics are less prominent in the SCF dataset. Questions of infrastructure governance and possible improvements to infrastructure, on the other hand, are more frequently discussed in SCF. Denouncing others, such as neighbors or parking offenders is also less prevalent in SCF (Table 23, bottom left).

It can be speculated, that these differences in the submitted reports result from the more private, one-to-one type conversation between the reporting citizen and the city in comparison to the more social and discursive nature of SCF. Many users might prefer to report small incidents of Graffiti, litter, or traffic violations in the more anonymous setting of CCN, but might hesitate to post them on SCF, where they might need to justify their posting in front of other users. Examples of arguments among users exist on SCF, especially in the context of parking disputes.

Tone of the Reports

Another question of interest was the mood and tone of language used in the textual descriptions. The majority of reports submitted to both systems were written in a neutral, factual language, very critical, or otherwise emotionally colored reports are rare (Table 23, top right). The proportional composition is remarkably consistent across the two compared platforms. Often, and more so in SCF, reports are written in a somewhat critical tone to express the urgency of the issue. Again, the more public nature of SCF might contribute to the higher proportion of critical language to mobilize other citizens. In both systems, reporters can submit a geo-referenced image of a graffiti tag or a pothole without any description, if the issue is sufficiently represented by the image. This is the case for 15% of SCF reports, and 20% for the mostly mobile-submitted CCN reports.

Table 24 Tone by incident type, Citizens Connect (CCN) and SeeClickFix (SCF). Trash / litter related issues often prompt very critical reports on CCN, while on SCF, this is mainly the case for infrastructure repair issues.

SCF - tone by incident type	very critical		critical		neutral		no text		plea		friendly		Total	
	CCN	SCF	CCN	SCF	CCN	SCF	CCN	SCF	CCN	SCF	CCN	SCF	CCN	SCF
animals	3%	0%	2%	0%	2%	2%	0%	0%	0%	0%	0%	3%	1%	1%
graffiti	5%	0%	4%	0%	17%	4%	38%	1%	11%	0%	6%	0%	18%	2%
ice	0%	0%	4%	1%	2%	0%	6%	0%	6%	0%	0%	0%	3%	0%
infrastructure improvement	0%	0%	5%	12%	3%	15%	0%	0%	5%	50%	9%	31%	3%	13%
infrastructure repair	28%	64%	43%	34%	44%	65%	50%	99%	44%	45%	39%	53%	42%	68%
other violation	13%	5%	9%	2%	2%	2%	0%	0%	0%	0%	9%	3%	3%	2%
plants	0%	5%	4%	1%	4%	3%	0%	0%	14%	0%	7%	0%	4%	2%
social issues	5%	5%	2%	2%	0%	1%	0%	0%	0%	5%	0%	7%	1%	1%
test / unknown	3%	0%	0%	0%	1%	0%	2%	0%	0%	0%	0%	0%	1%	0%
traffic	3%	16%	10%	7%	6%	6%	0%	0%	0%	0%	11%	14%	5%	6%
trash / litter	29%	16%	31%	9%	18%	2%	4%	0%	20%	0%	15%	7%	18%	4%
Grand Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Critical and very critical reports in CCN were triggered especially by trash and litter related issues; in SCF this is mainly the case for infrastructure repair issues such as potholes (Table 24). Neutral reports and reports without text overwhelmingly concern infrastructure repair, and in the case of CCN, graffiti. In both platforms, reports written in a more positive tone frequently offered suggestions for improvements.

Reasons for Submitting, Motivations Expressed

The reporters' motivation for submitting is estimated given the nature of the incident, the tone of the report and the explanation provided. The most common motivations were categorized as in the bottom left part of Table 22. While the behavior of other people is also a frequent reason of complaint on SCF, users of CNN report such issues more often. Users of SCF bring up general civic issues and explicitly raise safety concerns more often; also suggestions for improvements are more frequent. Because of the more frequent lack of text descriptions, CCN has a higher proportion of reports where no estimation of the reporter's motivation was possible.

This difference can be attributed to a number of reasons. Besides the already discussed difference in visibility, CCN, representing the city, tends to receive reports that have the character of service requests. SCF, on the other hand, is not directly identified with the city, and therefore attracts more discursive reports, focusing on infrastructure as a public good. In CCN, a pothole report often contains just a picture. In SCF, such reports are more often accompanied by complaints or warnings of safety implications.

Examples

The following section discusses the classification and inference of motivations from the reports in further detail. The tone of a report was categorized as critical if it contains language that expresses the urgency of an incident, or expresses mild dissatisfaction with how the city has handled the issue in the past. Examples include texts such as "*3rd report of crumbling stairway. Getting very dangerous*" or "*Light goes out periodically then comes on slowly. Dangerous area for drugs, assaults.. Please fix. Thanks*". "Very critical" are reports that use strong language to express dissatisfaction or choose an openly accusatory tone. Examples include complaints such as "*Case open 136 days. Come on, City of Boston, surely you can do better than that!*" or "*Paint* *the white lines. It's horrible that the lines have been missing here for over 1 year. You are on notice, if someone gets hurt the city is liable. Shame that there is a school 20 feet away....."* Reports categorized as "Pleas" urged the city to take action rather than just reporting facts, while "Friendly" reports used distinctively polite or humorous language such as *"Turkey walking down Fairfield street. Not winning the marathon..."*

In many cases, the estimation of motivations was not possible due to the briefness and factual nature of the report. Aesthetic concerns behind a report were only assumed if the reporter expresses or implies such a motivation, as in *"trash collects along this fence and is an eyesore. please send someone to clean it up. thx."* Graffiti, an aesthetic issue, was not automatically categorized as such a concern, as it might be reported for different motivations, such as a safety concern. Often, the justification was a bad personal experience: *"This pothole was never fixed, but reported fixed by City. I lost a tire on this pothole."* Frequently, public safety is invoked: *"This water cover has been unscrewed and turned over for a few days now and it's really pretty easy to trip on because it moves and stick up out of the sidewalk."* or *"This is a terrible intersection. Constant beeping every 5 mins disturbs the neighborhood. I'm afraid there will be an accident here all the time. I've almost been hit several times."*

There were also reporters that offered ideas and suggestions how to improve a specific situation, for example: *"Google maps says this area is a park. Doesn't look like a park to me. This area has one of the best water views in Boston and looks awful. There should be a park bench or something nice there. Also the guardrail is very old looking and beat up. Makes the neighborhood look disgusting. The whole area is very un-looked after,"* or *"Fallon field playground climber has come undone. Requires big-ass tamper-proof torx bits. I think that's all that's needed."*

Accountability is frequently directly addressed especially if an issue persists: "*Whoever got paid to close this report ripped off the taxpayers TWICE*". A resident of East Boston addresses issues of perceived inequality, writing *"Does one have to live in a posh neighborhoods to get something done? Isn't an abandoned U-Haul truck a security concern?"*

Often, the reason of complaints was the behavior of other citizens. Reporters denounced other citizens mostly in in disputes over parking or the handling of trash, but also over noise, code violations or other disputes. Examples include *"Mitt Romney's giant Shredder Truck illegally parked outside his office on Commercial Street. This giant shredder truck often parked in tow zone in front of Romney National HQ, yet never towed or ticketed. Maybe he's shredding the parking tickets too?"* or *"At 6:58 am today I ordered coffee at City Feed at corner of Centre and Seaverns St. The cashier coughed into her hand then proceeded to wait on me without washing her hands. This is unsanitary as well as disgusting behavior. Something needs to be done about this germ-spewing menace. Thank you."*

In addition, social issues beyond the scope of the public works department are raised, especially homeless and panhandlers are the targets of blunt requests such as *"PANHANDLER / BEGGAR [...], holding door open (to tracks 1 and 3), implying he's asking for money. I shouldn't have to put up with this while I'm paying $235 a month for my commute. Please have him removed and reinforce he should seek assistance elsewhere."*

Often, multiple issues, including aesthetic, safety and social concerns were addressed in one single report: *"Graffiti on the red sign and overall deteriorated building... Can't we do something to make the owners of this falling apart business take care of graffiti, trash, danger hazard of falling awning?"* For this reason, certain aspects were coded as non-exclusive properties in addition to the exclusive categories (Table 22, bottom left).

Private interests vs. the public good

Are the submitted concerns more personal, or more socially oriented, motivated by a personal grievance or by a concern for the public good? While both motivations might be present at the same time and difficult to untangle, the question whether concern for others plays a role in the submitters motivations does have implications for the design of the feedback system and vice versa. For example, personal complaints might be more effectively addressed by a minimalist system, while a concern for the public good may also be instigated through the design of the system.

Most reports are submitted in the reporter's own neighborhood (Table 20). Reports citing bad personal experiences or denouncing other people behaviors could be seen as personal complaints, while concerns for safety, public health and sanitation, or the discussion of wider civic issues addressed could be seen as public concerns. In this respect, about a third of the SCF reports and almost a fifth of the CCN reports are socially oriented; while only about 10% on each platform are explicitly personal in their motivation. However, the boundaries between personal and public are fluid – a private concern can quickly become a public concern if it resonates with the experiences of others. A report on SCF about a "stolen" parking spot quickly turned into a broad discussion about social norms that should be applicable in a comparable situation.[37]

Concluding with regard to RQ2, the differences in stated user motivations between CCN and SCF can be attributed to three different factors. First, the expectations of the user from the service: while both systems forward their reports to the city in the same way, SCF might be seen more "independent" from the city, and therefore receive more critical reports, but also less plain service requests. Second, the higher public visibility and lower privacy of reports on SCF might contribute to a different style of reports. SCF reports put more emphasis on the public

[37] The discussion can be accessed at http://seeclickfix.com/issues/76867

good, and the implications of infrastructural issues on the wider public. Third, the different affordances of the medium, the many-to-many conversation in the web environment leads to a more open-ended discussion in SCF compared to CCN. This third aspect will be closer examined in the following section.

RQ3: transformative effects

The effectiveness and the design of feedback systems are constrained by the capacity of city departments to respond to this feedback. The feeling that the city's capacity to respond to requests does not match the sophistication of the interface will create frustration and disaffection. Such a sentiment can be observed in several requests in the sample: *"72 days ago I posted this under case id 101000405068 city forward info and details to DCR and forgot about it 72 days later nobody even care about this. What is the purpose of this citizens connect if we voters are not taken in consideration by just simply being ignored [...]"*

As briefly discussed earlier, the design and configuration of the system allows the city to manage expectations and constrain the nature of citizen requests. It can be expected, that the capacity of the city to address citizen reports is reflected in their response time to specific types of request, depending on both the actionability of the request and its priority for the city given their constraints. The following section will therefore focus on the responsiveness to different types of requests.

Responsiveness of the city

Table 25 Citizens Connect: average response time by the city in days for closed issues, grouped by different categories (N=849)

Service category	Days open Mean	Days open Median
Graffiti	17.3	7.3
Other	16.8	1.5
Streetlight	13.0	3.8
Damaged Sign	12.4	8.7
Pothole	3.1	1.3
Sidewalk Patch	2.9	0.9
Unshoveled Sidewalk	2.6	2.8
Roadway Plowing/Sanding	1.5	1
Total	**13.0**	**2.0**

Incident type	Days open Mean	Days open Median
Plants	37.9	2.0
Social issues	35.0	1.8
Infrastructure improvement	19.8	8.2
Graffiti	17.7	7.3
Infrastructure repair	15.7	2.1
Other violation	11.1	1.2
Trash / litter	2.5	1.0
Ice	2.4	2.3
Traffic	2.4	0.9
Test / unknown	0.7	0.7
Animals	0.6	0.6
Total	**13.0**	**2.0**

Motivations expressed	Days open Mean	Days open Median
Ideas / discussion civic issues	31.2	6.6
Safety concerns	22.2	3.1
Concerns with disrepair	18.7	2.0
Bad personal experience	13.7	1.1
None specified	11.4	3.7
Aesthetic concerns	5.1	0.9
Issue with other people's behavior	3.7	1.2
Dissatisfied with the city service	3.4	0.8
Public health / sanitary concerns	1.9	1.3
Total	**13.0**	**2.0**

Tone of report	Days open Mean	Days open Median
Friendly	20.8	3.2
Plea	16.2	1.5
Neutral	14.3	1.9
Critical	13.6	2.0
Very critical	10.1	0.8
No text	7.4	2.8
Total	**13.0**	**2.0**

Table 24 shows the responsiveness of the city for reports submitted via CCN, measured as the average number of days until an issue is marked as resolved. A similar analysis was not possible in SCF, since issues are acknowledged by the city, but rarely marked as closed. Graffiti and other requests take average of 17 days (med=7.3) to resolve, while potholes, sidewalk patches and snow and ice removal are closed after three days or less.

An investigation of the nature of the incident reveals that issues that cannot be directly translated into an immediate course of action take longest to resolve, including suggestions for infrastructure improvement or social issues. In contrast, issues such as traffic and parking violations, are resolved swiftly (Table 25, top right). The tone of the report appears to make a difference. Reports in a very critical language are resolved most quickly, while friendly requests take longest (Table 25, bottom right). A similar pattern emerges from the motivations expressed: ideas offered and discussions of general civic issues tend to remain open longer (Table 25, bottom left).

Responsiveness is not the only measure for service quality; it can be expected that reports addressing larger questions cannot be resolved within a day. The time until resolution does however indicate the priorities of the city: city employees confirmed in a conversation that sidewalk patches have a high priority. It does also indicate how actionable a specific issue is: in terms of the nature of the incident, but also in terms of the alignment of the categories offered by the platform with the organizational structures inside the city government.

Integration with the internal structures

From the service provider perspective, the level of integration with the organizational structures of the departments is the single most important parameter for the success of a citizen feedback system. A free-form request might be convenient for the citizen, but is difficult to parse and act upon on the provider side. On the other hand, using internal service categories for requests might be most actionable for the city, but opaque for the citizen. A successful system negotiates between the two extremes, often leading to different results for each city. At this point open311 does not provide a standard taxonomy, instead offers functions to query the service types available in a specific location.

The compared systems choose different approaches in this regard. The DC 311 mobile application uses no less than 87 service categories. Citizens Connect offers seven frequently used categories plus a category labeled "other," covering everything else. Cambridge limits reports to six fixed categories. SeeClickFix adopts the categories of partnering cities, otherwise provides no standard categories at all.

The importance of integration also becomes apparent in the case of SCF: the system is effective where a partnership with a city exists, and the offered service categories is integrated in the structures of the local provider, as in the case of Boston since Sept. 2011. With no such partnership in place and no obligation for the city to respond in a timely manner, the system has to rely entirely on mechanisms of social accountability. Judging from the few reports submitted in Cambridge via SCF and the even fewer responses from the city, this seems to be often less effective and is detrimental to the trust into the system.

The categorization of reports also has tangible consequences for the organizational structures of public works departments. In the case of NYC 311, the requests prompted internal questions such as: how deep does a pothole have to be to fall into the responsibility of the department of sanitation as opposed to the department of transportation? Through the interaction with citizen requests, the departments re-negotiated their boundaries and relationships by repeatedly "drawing lines in the sand" and therefore re-shaping the system and its service categories.[38]

To what extent can a system facilitate self-help?

The capacity of online 311 systems to galvanize coordination and self-help among citizens is frequently emphasized. In fact, many of the reports submitted via CCN, fall outside the city's responsibility, or would not require its involvement: *"Our neighbor always brings her daughter and dogs to poop in front of our house and they live in 433 in the 1st and 2nd apartment. I called the Animal Control for 2 years and nothing changed."* It also is clear that a suggestion by a citizen to remove a handicapped parking spot cannot be negotiated over a system such as Citizens Connect. While many cases illustrate the need for a better coordination among citizens, systems

[38] From an interview with a former NYC 311 analyst

such as Citizens Connect in its current form are not designed to support such a many-to-many communication involving both citizens and the city. In order to allow citizens to act upon existing reports, these need to be visible and discoverable for other residents. SeeClickFix provides a simple mechanism for this purpose. Citizens can sign-up themselves or others for a "Watch Area", an automatic data feed of current issues related to a specific topic and neighborhood. Since SCF treats citizens and government as users on the same level, it is not predetermined that a request has to be addressed by a public official, it can also be answered by a citizen. During a large snowstorm in Boston Feb. 2009, this mechanism has become the basis for a citizen-initiated platform to organize the snow removal within the community.

Conclusions

As demonstrated, the design choices of citizen feedback systems – such as which aspects of the system are represented and how, which forms of interaction are allowed - play a subtle, but central role in mediating the interaction among citizens and between citizens and the city. This happens through various mechanisms. First, by determining the degree of the public visibility of a citizen report, as well as the degree of privacy of the reporter. Second, by encoding the representation of the participants in the interaction between city and citizens. Third, by regulating the interaction, for example by determining who is allowed to respond to a report. Forth, by providing the vocabulary of the exchange, for example by through the selection of categories that can be used for reporting. While current citizen feedback systems are not the final answer to the question how to engage the public in infrastructure governance, they offer valuable lessons on how this issue can be approached. Public participation is not only concerned with large questions and consequential decisions, but also with issues that happen on a very small scale.

The previous discussion identified a number of different examples of how design shapes such low-threshold interactions at the interface between the individual and an infrastructural system. The way citizens can engage with the city and its infrastructure is moderated through subtle design decisions that control visibility, access and the social dynamic among volunteers. Contrasting the design aspects of currently operational citizen feedback systems with different characteristics of the actual reports submitted by the citizens, it reflects on the role and significance of infrastructure legibility. How important is seeing the system? How important is seeing other people? How important is it to see the consequences, such as the responses from the city? In cases when citizens need to address an infrastructural issue they are suffering from, a simple and effective reporting mechanism, with the obligation of receiving a timely reply is highly appreciated. However, there are also many cases where the minimalistic approach is not sufficient.

While the value of civic participation is rarely critically questioned, it is also important to consider its possible downsides. A feedback system might reduce the perceived role of the city in answering citizen requests. Over-emphasizing the service character therefore can possibly paralyze the city, and ultimately diminish the quality of public infrastructure, especially with short-term fixes superseding more strategic, long-term planning. The same issue can be lead to frustration on the side of the citizen if the city is not responsive, follows a different agenda, or does not take responsibility for its actions.

When we talk about possibilities of digital technologies to facilitate democratic participation, we usually think of finished tools and systems that are widely used and in full operation. However, also the underlying protocols and design choices that define such systems have to be negotiated. The ongoing evolution of the open311 standard and its various implementations demonstrates how such a new form of public participation can take shape.

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Appendix

Table 26 Coding Rubric for content Analysis

	Operational definition
Tone of the Report	
Very critical	The report contains explicit expressions of anger, dissatisfaction or accusations
Critical	The report emphasizes the urgency of the reported issue
Neutral	The report is limited to factual information, for example an explanation of what needs to be fixed or a location description
No Text	The description field contains no text
Plea	The report contains language that urges the city to respond to the issue
Friendly	The report contains very positive language, such as a praise for the city's service
Incident Type	**If multiple issues present, identify the most salient**
animals	Incident involves animals – rodents, dead animals on the street and similar.
graffiti	Incident concerns graffiti
ice	Incident concerns snow and ice on the road or on the sidewalk
infrastructure improvement	Incident concerns possible changes to public infrastructure - new regulations, signs, elements
infrastructure repair	Incident concerns a state of disrepair, i.e. a pothole, a broken streetlight
plants	Incident involves plants - fallen trees, overgrown weeds and foliage
social issues	Incident involves a conflict with other social groups
test / unknown	Incident has no apparent purpose, or is sent to test the system
traffic	Incident concerns traffic issues, including parking violations
trash / litter	Incident concerns litter, trash and general cleanliness
other violation	All other types of incidents
Motivations expressed	**If multiple motivations are stated, identify the most salient**
aesthetic concerns	Report contains a concern for the aesthetic appearance of the city (graffiti is not necessarily always an aesthetic concern)
bad personal experience	Report mentions a bad personal experience in connection with the incident
concerns with disrepair	Report states that a physical object is broken
dissatisfied with the city service	Report contains explicit expressions of dissatisfaction with the city service
ideas / discussion civic issues	Report proposes a specific idea, or raises a more general civic question in relation to the reported incident
issue with other people's behavior	Report explicitly denounces another person's behavior
none specified	No reason can be inferred
public health / sanitary concerns	Report explicitly states a concern for sanitary or public health conditions
safety concerns	Report explicitly states that the issue poses a safety threat for the public
Non-exclusive Properties	
Demanding Accoutability	Report emphasizes accountability, for example by mentioning that the city has the obligation to the public to fix a specific issue
Reporting other people	Report explicitly denounces another person or party
Concern for safety	Report mentions a concern for safety
Suggesting Improvements	Report offers concrete suggestions for improvement