Forager - Designing Location-Aware Applications for Informal Waste Recyclers in Brazil

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Abstract
Informal waste collectors can provide recycling services to developing cities, while cities seek better data collection and stewardship of their waste systems. Mobile applications can mediate this relationship, but must be accessible and adopted by informal workers. Based on past work with recycling cooperatives in Brazil, we built and tested Forager, a web and mobile platform for co-ops to track their own collection vehicles in real-time and improve coordination and transparency with their private partners and local government. Through observations, workshops, and interviews, we identified simple, error-tolerant, unobtrusive interfaces as ideal for informal work environments. Finally, we discuss how security, workload, and user expectations present unique opportunities and challenges for pervasive urban applications in developing contexts.

Author Keywords
Informal sector; Participatory design; User-centered design; Prototyping; Mobile app; Web app; Waste management; Case study.

ACM Classification Keywords
H.5.2 [User Interfaces]: Prototyping; User-centered design; H.1.2 [User/Machine Systems]: Human factors; H.4.2 [Types of Systems]: Decision Support; Logistics.

Introduction

Informal economies, such as those based on waste picking and recycling, provide many needed goods, services, and jobs in cities in the global south. Waste pickers divert useful recyclable material away from general waste streams, reducing the burden on municipal landfills and waste management [1]. Despite poor working conditions and financial vulnerability, waste pickers are able to subsist and sometimes thrive from the sale of recyclables to industry. A growing number of countries acknowledge their informal workers, support their integration with the formal economy, and encourage public and private institutions to contract services from waste cooperatives. This approach focuses on creating new opportunities for waste-pickers to modernize on their own terms [2].

New federal legislation in Brazil recognizes them as a central part of the value chain, and offers them access to government and private contracts [3]. However, these opportunities come with challenges; the regulations also include strict requirements for tracking waste flows and product life-cycle information. To compete for lucrative contracts, cooperatives need to be able to plan and document their own processes amidst greater demands for transparency, service efficiency, and data quality [4].

This demand for prompt, accurate data can be met by adopting new technologies, such as smartphones and location-based applications. Mobile phones are already well-used and valued by the poor as tools of economic survival [5]. However, designing digital tools for cooperatives can be a considerable challenge. As communities of practice based on tacit knowledge, they mostly rely on informal organization [6]. New technologies need to respect the unwritten rules within these vulnerable organizations.

The goal of this paper is to present new opportunities, experiments, and lessons for supporting informal waste management in modernizing cities using mobile applications. We develop and test a system for a recycling cooperative to track the locations and activities of their collection trucks in real-time, called Forager. Our work addresses three questions: 1. How can location-aware mobile technology support informal waste cooperatives, and integration into urban waste systems? 2. How should we design such technology to maximize adoption by and usefulness to its users? 3. What are the implications for pervasive urban applications in sustainable waste management?

Related Work

Mature tracking systems are used in many logistics fields, such as package delivery and formalized waste management. Real-time tracking and routing technologies arose in response to “Just-In-Time” procurement practices and on-demand consumer delivery needs from electronic commerce [7]; widely available GIS software and GPS hardware formed the foundation for such applications [8]. The generated data are used in shorter feedback loops to guide vehicles efficiently within their shifting daily context, and in longer feedback loops to guide decisions on fleet and labor management, route planning, and infrastructure build-out [9]. For instance, package delivery service U.P.S. claimed to reduce fuel use by three million gallons in one year, by identifying the relative inefficiency of making left-hand turns and eliminating them from truck routes [10].

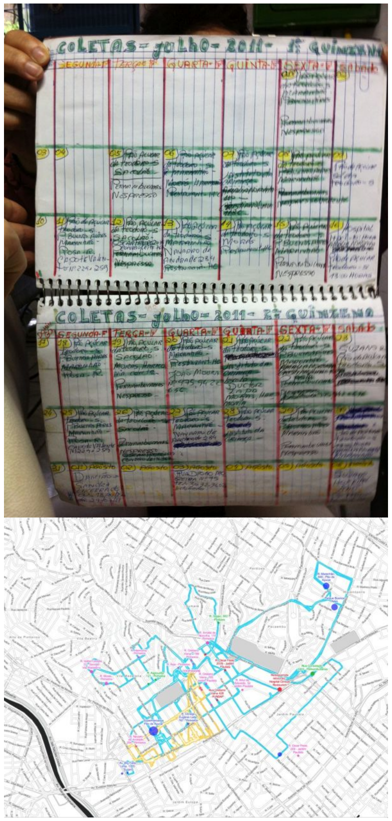

Figure 1. Top: Client pick-up schedule for a Sao Paulo recycling cooperative. Bottom: The same information mapped with our application, along with GPS traces of their collection routes by truck and hand-cart.

Urban and transportation planners are finding value in gathering such data across all logistics activities in cities, to understand the flow of urban freight and mitigate congestion or environmental impact. Methods for collecting these data have evolved from surveys, to traffic sensing at key nodes, and finally to sharing of GPS-generated location data between firms and governments [11]. GPS tracking of municipal solid waste trucks in Thailand allowed planners to detect population changes in dynamic immigrant neighborhoods, gaps in waste service that were filled by informal workers, and growing waste generation rates that would soon outpace their truck capacity [12].

Many practitioners grapple with how to introduce these technologies to users unfamiliar with their capabilities. Location-based services, both those that inform the user of their location and those that inform others, have been broadly accepted by consumers for use in mobile applications, but only if the perceived individual benefit outweighs the loss of privacy [13]. Their use in tracking employee activities raises ethical questions of fair treatment [14], which we sought to understand in the context of informal cooperatives where there is less hierarchy between the workers.

In Brazil there are several ongoing efforts to develop technologies to aid small or informal waste handlers with logistical needs. One survey highlights the need for route planning support and better management of vehicles [15]. Researchers have also prototyped automatic data entry for electronic waste [16] and RFID tagging for hazardous materials [17], both under increased scrutiny by the federal waste policy. The success of these systems may determine whether informal workers are trusted to handle certain types of waste, while meeting the monitoring and regulatory needs of the broader urban waste system.

Case Studies

We have conducted a series of projects with recycling cooperatives in Brazil since 2011. These cases informed our problem statement and design approach to our subsequent Forager truck-tracking application.

In São Paulo, Brazil, we worked with an informal recycling cooperative to map their truck and handcart collection activities using GPS loggers. The visualized traces provided useful context for the waste pickers to explain knowledge that had never been codified, such as how handcart operators choose their routes. They also provided concrete evidence of the coop's operational challenges, such as congestion and driving restrictions acting as greater obstacles than distance. [18]

We also developed a mobile pick-up request application to encourage local businesses to donate recyclables. However, after seeing the platform in action, the coop inferred that the system would clash with their current practices. They noted that without a direct conversation, they would not be able to manage expectations for the timeliness of the pick-ups. They also preferred to encourage people to drop off material, to minimize their number of trips. Thus, the interfaces would be better off if reversed, with the cooperative able to broadcast their activities in real-time, and clients able to observe this information from the map [18].

In Recife, Brazil, we worked with the cooperative Pró Recife, who deal with local institutions and receive equipment and contracts through cooperation with the government. However, they must meet stringent requirements for documenting any electronic waste they encounter. We built a smartphone application that would help them tag and track such materials.

While testing the system, however, we quickly learned that our smartphone application was too complex, visually and sequentially, to be used effectively while working to collect materials. For subsequent tests, we had to prioritize user comfort and accuracy with the app.

We also discovered practical limits on applying this system to hand-cart waste picking. When asked to carry and test the smartphones on their collection routes, manual pickers declined due to risk of theft. Waste pickers already operate in less policed, often informal areas, and carrying around electronics could increase their vulnerability. While such technologies might work well from the cab of a truck, they offered more risks than benefits for some workers in contested areas.

Forager application

Through our interviews with Pró Recife, we learned that real-time vehicle tracking, a minor feature of our previous e-waste handling app, was actually much more relevant to their operations. Because traffic congestion and road infrastructure in Recife are highly unpredictable, and because they pick up materials from clients all over the city, their truck is active through the whole day. Communication runs through mobile phone, but some information such as their current location and changes to routes are difficult to transmit while on the road. The coop felt it could benefit greatly from seeing the vehicle's location in real-time on a map. Archiving these traces could also help them plan better routes, and document their collection activities in a form easily shared with their public and private partners.

Design challenges

Tracking technology – Cost and ease of procurement and maintenance are important factors for introducing any new technology, and coops lack the financial flexibility to invest in single-use technologies like dedicated location trackers. We needed hardware that would be easy to procure, easy to repair or replace, and relatively inexpensive to operate.

Financial uncertainty – What resources cooperatives have to test out new technologies often come from government initiatives, NGOs, or research grants. These are often restricted to a few years at the most, and political shifts may reduce or eliminate their funding. Cooperatives benefit from technologies that are free or inexpensive to maintain, and can be adapted and improved despite changing personnel.

Technological infrastructure – As an extension of this, computing resources in a coop could range from banks of networked computer workstations down to an outdated single PC. Internet access might consist of a local wi-fi network with broadband paid for by an outside partner, or a 3G USB modem relying on pre-paid mobile SIM cards. We had to account for a wide range of processing speeds, operating systems, internet bandwidth, and hardware set-ups in our potential user base.

Technical literacy – Because many informal waste pickers lack formal secondary education, we couldn't count on all users being familiar with the jargon and norms of information technology. Older workers might also be unfamiliar with recent features of mobile and smartphones, such as touch interfaces and built-in cameras.

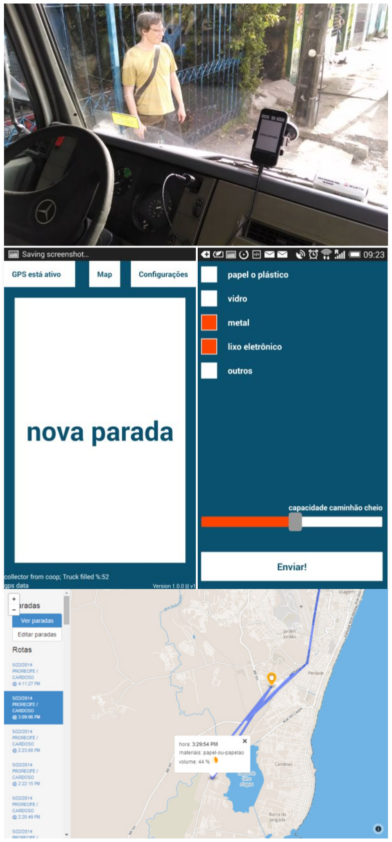

Figure 2. Top: Smartphone with truck tracking app safely mounted to inside of truck cab. Middle: Mobile app screens for toggling tracking and logging stops. Bottom: Web interface for mapping truck routes in real-time.

Field conditions – By limiting our tracking activity to the movement of collection vehicles, we addressed two earlier concerns of the collectors: keeping the phone out of view of would-be-thieves, and protecting it from exposure inherent to waste work. However, we were still faced with uncertain access to electrical power and mobile data networks.

Design choices

Because of these design limitations, we devised a system that relied on two simple interfaces: one to track collection activity in the field, and the other to view these data away from the field. The former would be installed on an Android smartphone capable of tracking its own position using internal GPS and a standard geolocation API, while also allowing users to manually input metadata such as the material collected and the fill level of the truck. The latter interface would be accessible by web browser, allowing users to map any of the location traces collected by the phone trackers in real time, and annotate the map to aid in route planning.

We designed the smartphone application to be simple to operate, with only three interface screens: one for turning on location tracking, one for detailing a pickup stop, and one for identifying the worker and coop. Buttons were sized by importance, primary colors indicated whether tracking was turned on or off, and data input at pickups required only approximate observations (broad categories for types of waste, and a visual slider for amount of material filling the truck).

Behind the interface were more complex functions for caching this information when a data connection wasn't available, and uploading it to a cloud server when in range of mobile or wi-fi networks. This was essential for ensuring that data would be saved despite unpredictable network access, while avoiding any complicated manual upload procedures and possible data loss or duplication. An external 11200 mAh battery provided additional charge life for over a full day of use, while mobile connectivity required a pre-paid SIM card from a Brazilian-based operator. Finally, we installed a windshield-mounted smartphone grip to hold the phone in place while driving.

As for the real-time map, we chose to develop a web application that would work consistently on most browsers, while allowing us to remotely update it with feedback from the cooperative after our deployment. This application was also kept visually simple, devoting its single screen to an online map showing a selected trace and a set of points-of-interest (usually waste pickup and drop-off locations). It would serve dual purposes: as a real-time tracking application by showing the most recent in-progress trace as it developed, and as an analysis tool for groups of workers to review past traces and identify areas of opportunity or inefficiency. It could easily be shared with clients or public partners as evidence of past activities as well.

Traces begin and end wherever the user starts and stops the tracking function, respectively, and from the web application side, the traces appear as polyline segments overlaid on a draggable, zoomable map. Markers indicate the stops made by the truck during its route, as well as the latest known position; mouse-over events show the timestamp of each stop, and click events display the waste types and fill as input by the workers. Additional markers show the various points-of-interest that the cooperative had previously annotated on the map.

Technology stack: The web application front-end was written in Javascript, using the Mapbox API and Bootstrap template to present the interactive map interface. The street layer of the map is sourced from collaborative OpenStreetMap data, visually styled using Mapbox. The smartphone and web apps used a common backend: Parse, a cloud-based model-view-controller application platform. Both apps benefited from a shared data object structure, shorter technology stack, and automatic data caching and upload in the Android SDK.

Experimental procedure

Our visit to Pró Recife focused on how to incorporate this technology into their workflow. This meant demonstrating the system with their workers, mounting the phone in their vehicle, setting up their office computer to access the web application, and sending their truck out for collection to observe their reaction to the interface. We monitored their use of the system remotely, through access to the web console and continued hardware troubleshooting. After several months of use, we followed up with a series of semi-structured interviews with the cooperative members to understand how the tool had affected their working practices thus far, and how they planned to use it going forward. Although the cooperative comprised of 29 members, they chose to have two members represent them in our interview: their truck driver and manager.

Results

From our database, we observed the cooperative running the tracking mobile application sporadically from May through October of 2014. Rather than incorporate the application into their daily practice, they chose to use it occasionally for specific purposes.

The driver indicated little experience with using web-based applications or maps, and neither he nor the manager owned smartphones. However, while training them to use our application, we did not observe any difficulty in running the app or navigating its interface. During our subsequent interviews, neither mentioned the interface as a challenge.

The driver said that he had begun using the phone's navigation app for locating addresses, indicating an improved familiarity with the smartphone overall. Additionally, the driver said the navigation app improved his ability to collect material. This was not a function we had intended when installing the smartphone in the truck, but the driver clearly valued it and justified having the system in place.

The manager also felt the system helped his work, citing "credibility, reliability, and transparency" as ways the system improved his relationship with the government. He also noted that they could negotiate more lucrative contracts with clients now. In his words, being a "pioneer" in this field and an "academic reference" provides them a great advantage in gaining "support for the cooperative." He intended to use the system on a daily basis, but in conjunction with new contracts with clients who would help fund its running costs.

He also reiterated his fears of theft or robbery of the phone, even when placed inside of the truck, and that this "third party might make personal use of the device." His request was to add password protection to the application, indicating that they wished to protect not only the physical hardware, but also the collected data.

Conclusion

How can location-aware mobile technology support informal waste cooperatives, and integration into urban waste systems?

New technologies enable cooperatives to apply real-time tracking and route optimization to their work, without having to adopt the strict command structures of formal businesses. They can choose tools that do not interfere with their current evolved practices, while collecting information that can be used to stabilize or improve their situation. This information requires less

Figure 3. Participatory Design workshops, where the cooperative members would gather to review the collected data and prototypes, revealed many of the deeper social and political challenges with designing technology for their environments.

formal training, infrastructure, and commitment to obtain than with commercial logistics technologies. Such tools can be scaled down to their needs, minimizing costs so that they can compete on equal footing with private companies for contracts.

However, cooperatives can also scale up to provide municipal solid waste services across the city through partnerships with local governments, by using those tools to make their operations transparent and easy to monitor for public officials. This transparency helps companies and governments hold the cooperatives accountable for their operations, at the same standards by which private waste operators are tracked. Having cooperatives take on the tasks at which they excel, such as recovering valuable materials and collecting in poorly mapped, informal communities, allows governments to focus on other problems, such as enforcing health and safety regulations.

Such hybrid formal-informal waste collection systems could offer the best of both approaches: efficient localized collection with minimal added infrastructure, employment for the most in need, transparency and accountability, and the preservation of tacit knowledge in communities.

How should we design such technology to maximize adoption by and usefulness to its users?
Basic ergonomic, technical, and environmental factors make it difficult to deploy technologies in environments such as waste cooperatives. These include glare from sunlight, exposure to dust or moisture, battery drain, signal coverage, and lack of charging infrastructure. These represent classic HCI problems that are not unique for informal environments. External batteries, protective casing, and data caching can improve the system's resilience in uncertain conditions.

Interface design techniques that reduce cognitive load on the user are all welcome. Simple interfaces with only a few sequential steps greatly improve user comfort and success with these systems. Minimal use of text and hierarchy in color and size also help workers quickly navigate the applications and devote more attention to their manual work. Data transfer between devices should be automatic and invisible.

Social challenges constituted the largest part of our work, due to the complex nature of how technology and the social practices in the cooperative affect each other. For example, fear of robbery strongly deterred manual collectors in Recife from carrying phones with them. This drove our decision to only track motorized vehicles using the smartphone application.

Social realities may also limit participation and our capacity to conduct HCI research and training. Workshops had to be as non-intrusive as possible, since any time spent with us would delay their tasks at hand. Cooperatives also preferred to limit interviews and surveys to those workers who would use the technology directly, rather than all members. Such constraints prevented us from testing across a large sample population, and forced us to focus on how the group as a whole might respond to the technology.

We frequently discussed the expectation of an immediate benefit versus long-term infrastructural payoffs; many cooperatives quickly dismissed tools that did not meet their needs or expectations. In this sense, mobile phones offered many flexible benefits, such as

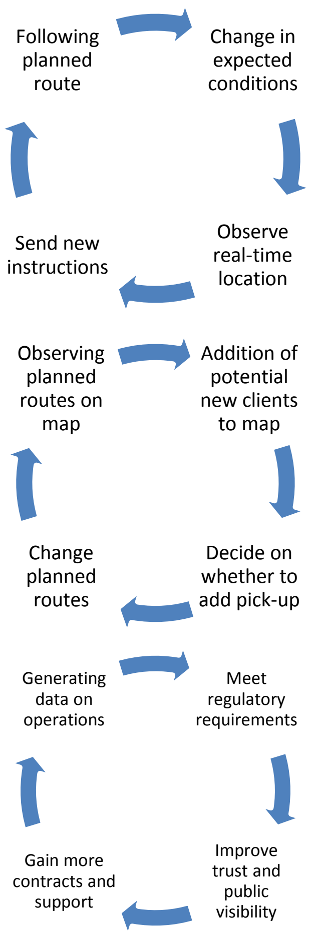

Figure 4. Location trace data helps the cooperative operate collection in the short term, plan routes in the medium term, and build trust and partnerships in the long term.

navigational tools, that help drive adoption and enable us to test other systems.

What are the implications for pervasive urban applications in sustainable waste management?
We see three types of feedback loops that can be closed using the information generated by tracking systems like the Forager application.

In the short run, real-time vehicle tracking can mitigate disturbances like cancelled or rescheduled pick-ups. A change in the itinerary or traffic accident can be communicated rapidly between the cooperative, collection crews, and clients. They can then alter the planned route of the collection vehicle, and monitor its progress for any further changes. Thus they can avoid wasted trips or missed opportunities that might result from a miscommunication or ambiguity.

In the medium run, the cooperative can use its data on material flows and client locations to plan better routes for its collection. New clients can be folded into existing routes or rejected based on the relative cost of picking up the material. The system as a whole can ensure the best use of limited vehicles and man hours, while retaining a steady and profitable flow of recyclable materials.

In the long run, the cooperative can comply with the demand for transparency from both public officials and private partners. The steady flow of operations data holds both sides accountable to their commitments; cooperatives can demonstrate their impact on waste management for the city, while their partners can identify where additional operational support is needed (such as vehicles, infrastructure access, or specialized training). This builds trust and visibility for the cooperative, and stabilizes their contracts and political support.

Summary
In this paper, we explored how technology can transform waste systems in developing cities, through the inclusion of informal recycling activities. We applied lessons learned from two prior projects using waste tracking technology to support recycling cooperative operations. This culminated in development of the Forager system for tracking collection vehicles in real-time. We concluded that location-based mobile technology can enable new ways of managing waste in developing cities, though there are many challenges to designing such systems in a participatory way.

Yet, the work of understanding informal waste pickers, their tacit knowledge, and importance to developing cities remains unfinished. Many cooperatives and individual pickers remain in precarious situations, and further technological innovations can help solidify their position in the formal waste chain. Future research should continue to take an action-based, participatory approach to building solutions that respect the independence and expertise of the informal sector.

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