UbiGreen: Investigating a Mobile Tool for Tracking and Supporting Green Transportation Habits

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ABSTRACT

The greatest contributor of CO_2 emissions in the average American household is personal transportation. Because transportation is inherently a mobile activity, mobile devices are well suited to sense and provide feedback about these activities. In this paper, we explore the use of personal ambient displays on mobile phones to give users feedback about sensed and self-reported transportation behaviors. We first present results from a set of formative studies exploring our respondents' existing transportation routines, willingness to engage in and maintain green transportation behavior, and reactions to early mobile phone "green" application design concepts. We then describe the results of a 3-week field study (N=13) of the UbiGreen Transportation Display prototype, a mobile phone application that semi-automatically senses and reveals information about transportation behavior. Our contributions include a working system for semi-automatically tracking transit activity, a visual design capable of engaging users in the goal of increasing green transportation, and the results of our studies, which have implications for the design of future green applications.

Author Keywords

Sustainability, transportation, ubicomp, ambient displays

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

In 2005, Americans consumed 100 quadrillion British thermal units (BTUs) of energy [32], almost six times the worldwide average per person [20]. This in turn caused the release of 2.2 billion metric tons of carbon dioxide (CO_2), a greenhouse gas assumed to be a major cause of adverse climate change. To reverse this trend, action will be required on many levels, including policy, infrastructure, and individual change. Given the growing prevalence of mobile phones with sensing capabilities, one compelling opportunity to potentially impact human behavior is to offer immediate feedback about how currently sensed behaviors affect the environment. In this paper, we explore the use of personal ambient displays on mobile phones to give users feedback about their sensed and self-reported transportation behaviors (Figure 1).

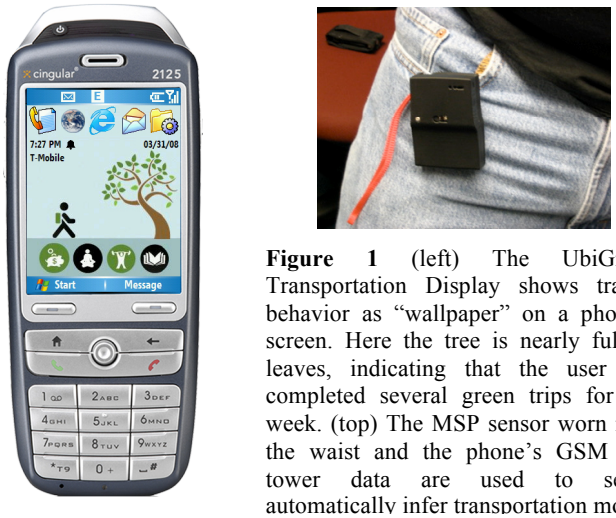

Figure 1 (left) The UbiGreen Transportation Display shows transit behavior as "wallpaper" on a phone's screen. Here the tree is nearly full of leaves, indicating that the user has completed several green trips for the week. (top) The MSP sensor worn near the waist and the phone's GSM cell tower data are used to semi-automatically infer transportation mode.

Researchers have identified three areas responsible for a majority of energy consumption in American households: home heating and cooling; shopping and eating (and the associated transportation of goods); and commuting, flying and other daily transportation activities [3,35]. In this paper, we focus on the latter (personal transportation), the greatest individual contributor of CO_2 emissions (26%) in the average American household [35].

There is extensive literature in the areas of environmental sociology, public policy, and more recently, conservation psychology that discuss the promotion of environmentally responsible behavior [1,2,26,33]. Past work has shown that motivators such as public commitment, frequent feedback, and personalization can positively impact environmentally responsible behavior [1]. Since the 1990s, information campaigns and other programs have attempted to engage individuals in voluntary greening of transportation behavior

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[2]. Programs and studies have explored issues from social marketing [26] to community-level interventions [2]. There is also literature to support the connection between increased personal awareness of everyday activity and behavior change. For example, in a review of over twenty studies exploring the effects of feedback on electricity consumption patterns in the home, the typical energy savings found were between 5 and 12% [15]. It is unclear, however, if feedback technology focused on transportation choices will translate into this level of reduction.

Computing technologies have begun to play a more substantial role in supporting green behaviors [15]. A-Life Tree[1] grows on the background of the user's PC depending on CO_2 sensors in the environment; however, this is *not* tied to personal actions. The RideNow project uses a website and email to help coordinate carpooling [34]. Professor Tanda uses a mobile phone to teach about environmental impact in context [7]. Other mobile applications support green transportation behaviors (*e.g.,* Carbon Diem[2] and Ecorio[3]), but little research has been conducted about how to successfully encourage green transportation choices using mobile devices.

Our work focuses on using technology to encourage green transportation habits among individuals who have a pre-existing interest in taking action to lessen their impact on the environment. Here, green transportation refers to any eco-friendly transit alternative to driving alone. We have built an application prototype for mobile phones, called the UbiGreen Transportation Display (Figure 1), which supports awareness of personal transportation activities, reminds users of additional reasons for being green (*e.g.,* financial savings), and reinforces their commitment to eco-friendly behavior.

We first report on two studies we performed to better understand current transportation behaviors: an online survey and an experience sampling (ESM) study [11]. Both studies focused on how we might engage individuals in green behavior. Based on participants' responses to early design concepts, we determined that feedback about green behavior on a mobile device would be of value and that an iconic representation of green behavior could be engaging.

The results of these formative studies inform the design of our UbiGreen Transportation Display, the first in a series of activity-based [23] UbiGreen applications for encouraging sustainable behavior. This prototype uses sensors and self-report to monitor transportation activities and provides feedback on the background of the user's phone. We describe UbiGreen and then present the results of a 3-week, 13 person field study. Our results help to illustrate the value of our designs. The primary contributions of this paper are:

1) A working system for tracking transportation behaviors and providing feedback on a mobile ambient display;

[1] http://www.nyu.edu/projects/xdesign/onetrees/description/index.html
[2] http://www.carbondiem.com
[3] http://www.ecorio.org/

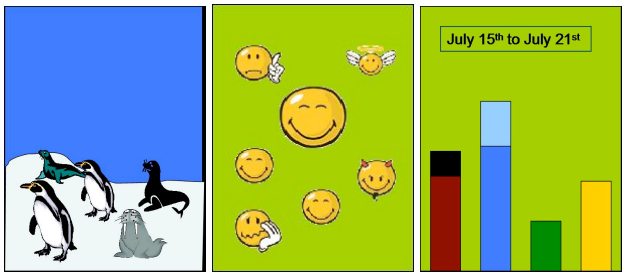

Figure 2 Three of the six early design concepts shown to respondents as part of the online survey.

2) A design capable of engaging users (as demonstrated by our study) with the goal of increasing their green transportation, based on a series of formative studies exploring the value of different design dimensions; and
3) A qualitative analysis of a 3-week deployment of our system, resulting in new ideas for increased social interaction, engagement and motivation.

STUDIES OF TRANSPORTATION HABITS

We conducted two formative studies, an online survey and an experience sampling study, that investigated, among other things, the respondents' willingness to shift to more eco-friendly transportation, their motivations for driving, and reactions to different visual representations of transportation behavior. The experience sampling data was gathered using a combination of complementary techniques: signal-contingent sampling, diary reports and photos [4,9,18]. The studies supported the user-centered design process in developing UbiGreen by giving us early feedback on our visual design concepts and on the user experience of wearing and interacting with our system for tracking transportation behavior. In addition, data from the experience sampling study helped refine our transportation inference algorithms and visualization design.

Online Survey

The goal of the online survey was to determine people's attitudes regarding green transportation and get feedback on early visual design concepts.

Survey participants were recruited through a popular online classified ads listing service in Seattle. Respondents received a $10 gift certificate for completing the survey. Our recruitment materials stated that we were interested in "transportation practices in our community" and would be using this study "to design mobile technology to help people travel in a more environmentally-friendly way." Our goal was to reach individuals interested in using green forms of transportation, as they would be representative of the potential users of the tool we planned to build.

A total of 63 respondents (78% female) completed the online survey in July and August 2008. Respondents represented a wide range of occupations and included a flight instructor, school bus driver, students, managers, scientists, and stay at home parents. 42% of respondents lived in large cities (i.e., cities of more than 500,000 people); the rest lived in towns and smaller communities.

The online survey was divided into two parts. The first section asked respondents about their transportation habits, including the frequency with which different modes of transportation were used and what influenced their choices. The second section, which could not be viewed until the first section was complete, explored design concepts for a mobile tool to encourage green transportation choices (Figure 2). This section explored a variety of design dimensions such as comparative versus personal data and iconic versus numeric representations.

Online Survey Results

The online survey helped us understand how people make transportation decisions, their willingness to engage in green travel, and their reactions to our application design concepts. We discuss each of these areas in turn.

Why respondents drive: Similar to past research [17], we found a number of factors underlying a person's choice for transportation. When asked about the most important factors when selecting transport, 77% of respondents selected time to destination, 67% selected flexibility, and 47% selected cost. Combining travel with exercise was mentioned by 13% of respondents. When asked about reasons for driving by car, 45% of respondents reported that not driving would take too much time, 51% that public transportation was unavailable or impractical, and 57% said that they needed the car to carry things. Our results suggest that if obstacles to *not* driving could be overcome, motivations other than eco-friendliness could be used to motivate green travel.

Willingness to engage in eco-friendly travel: While only 19% of respondents reported that being environmentally-friendly was one of their top three priorities when making transportation decisions, 72% would be willing to set goals for themselves to travel in a more eco-friendly way. Fewer than half of the respondents (45%) thought that they were doing everything they reasonably could to travel in an eco-friendly manner. Furthermore, 61% had taken *at least one action* with the direct goal of making their transportation more eco-friendly. Popular actions included driving only when necessary, combining multiple errands into one trip, driving a hybrid or a fuel-efficient car, trying to walk more and making better use of public transportation. Of this group of respondents, 63% claimed to have maintained these eco-friendly travel choices over time.

Reactions to application design concepts: Half (52%) of respondents were interested in having feedback about eco-friendly travel on their phone, including how they did in relation to others in their city (71%). However, 54% were unwilling to share this data with others (familiar or strangers).

With regards to visual feedback preferences, respondents were almost equally divided between iconic (50%) and numeric (47%) representations. Iconic representations used an abstract image or metaphor to indicate green behavior in some way. Numeric representations used text or a bar graph. An abstract image provides less information but may add other potential benefits such as evocativeness or aesthetics, depending on its design [10].

These results indicate that our respondents were receptive to change and would be willing to use a system like the one that we propose in this paper.

Experience Sampling Study

After the online survey, we ran an experience sampling study using mobile phones to see whether people's in-the-moment reasoning about their transportation choices were consistent with the results from the online survey, and to get feedback on the early designs of the transportation sensing and visual design components of our mobile application. We also used this data to help calculate how many green transportation actions people took in a week.

Seven people (five female) from the Seattle area volunteered to participate in the one-week study. Participants were recruited from among our acquaintances that were interested in green travel and were willing to work with an early prototype; six were graduate students and one was a software developer. Participants were loaned a Cingular 2125 Windows Mobile phone running the MyExperience software [18], and also carried their personal mobile phones. MyExperience automatically triggered short self-report questionnaires on the mobile phone based on the participant's movement. These questionnaires asked about current location, the method used for transport, and, depending on the response, a series of questions about that particular transportation method. For example, if the participant had just driven somewhere alone, we asked about eco-friendly alternatives and the circumstances under which the participant would be likely to use these alternatives. We ended with exit interviews where we demonstrated our design concept and got user feedback.

Automatic trip detection was done by looking for significant changes in the visible GSM towers on the phone, which allowed us to detect trips of about half a mile or longer. Participants were asked to manually trigger a questionnaire in cases where the automatic trip detection failed and to take camera-phone pictures of anything that illustrated the experience of their daily travel (average of 14 photos per participant). This approach allowed us to test our trip detection and get situated data early in our design process with a minimum of development time, which is difficult to do in ubiquitous computing research [6,9].

Experience Sampling Study Results

Participants reported an average of 18 trips for the week (min: 11, max: 24). The majority of trips taken by our mobile participants were green, with walking being the most favored green transportation method. 34% of the trips were taken on foot, 26% using a bicycle, and 15% using public transportation (buses or ferry). When the participants did drive, their reasoning was similar to the reasoning provided by the survey respondents. Out of the 34 car trips total for all seven participants, they claimed that it would have taken too long not to drive for 13 of the trips (38%) and that they needed the car to carry things for 11 of the

trips (32%). Also similar to our survey results, for 73% of all car trips, greener transportation options existed.

This study also helped reveal the hidden complexities behind the perception and selection of a transportation mode. One participant noted in the exit interview that when biking for transportation, he did not think of it as exercise. Reframing short trips as an opportunity for exercise could potentially make a difference in selecting vehicular travel vs. healthier (and more environmentally friendly) options. If a participant indicated in an ESM survey that s/he drove, we asked if bicycling or walking were viable alternatives. In those cases when bicycling or walking were indeed viable options, our participants reported 52% of the time that they would have been more likely to select bicycling or walking had they thought of health benefits (e.g., caloric expenditure) when making the travel decision.

Finally, the participants were shown an early version of our design concept for a mobile phone application—an icon-based design representing green activity with a growing tree (similar to the tree design in Figure 1). All were able to understand the interface elements without prompting and were positive about having such a representation of their transportation activities on their mobile phones.

Design Implications of Online Survey and ESM Study

Our formative studies suggested that users could benefit from a mobile application that provides awareness of transportation routines and that they would be interested in such an application. Given the range of considerations that impact transportation choice, a design need not focus solely on emphasizing green behavior and may incorporate auxiliary benefits such as cost and health. Other factors such as stress, ability to do other things while traveling (*e.g.,* reading) may also be relevant. Prior work [17] also underscores the many factors that affect transportation choice—not all of which are environmentally related. We highlight these secondary benefits in our design.

Although initially we were interested in building a social-mobile application around green transportation behaviors, our participants' ambivalence about sharing information led us to focus on a single-user application. We plan to explore multi-user applications in future research.

As users did not express a preference between the iconic representations *vs.* numeric representations of transportation behaviors in our online survey data, we decided to use iconic representations for our mobile application. Prior literature enumerates a few of the advantages of iconic visual displays: (1) they may be more aesthetically pleasing in a peripheral viewing situation [31]; (2) once learned, they can easily and quickly convey glanceable information [24]; and (3) they may evoke other responses such as emotional attachment [13,14]. However, iconic representations often do not offer the same level of detail as their numeric counterparts.

UBIGREEN MOBILE APPLICATION

Based on the results of our formative work, we created the UbiGreen Transportation Display, a mobile phone-based application that provides personal awareness about green transportation behaviors through iconic feedback. Small graphical rewards are earned by taking "green" transportation such as riding the bus or train, walking, biking, or carpooling. Although each of these activities has different CO_2 emissions, we counted them equally, as each is preferable to driving alone. Once a green transit activity is sensed, the background (wallpaper) of the user's phone is updated accordingly. A phone's wallpaper represents a critical area of screen real estate as it is seen nearly every time the device is picked up and used. In this way, the wallpaper functions as a type of personal ambient display [9,24].

Our designs are partly based on a finding from social psychology that cognitive representations of different concepts become linked if those concepts are repeatedly encountered together [21]. We take advantage of this fact by jointly presenting a representation of eco-friendly transportation and representations of other goals—such as saving money, getting exercise, etc.—that the user may care about. The interface emphasizes these sub-goals automatically when green transportation is taken.

We were also influenced by research in conservation psychology that showed how caring for animals helps humans connect with nature [25]. Dillahunt *et al.* adapted this notion and explored how "virtual polar bears" could be used to motivate green behaviors [13]. They found that

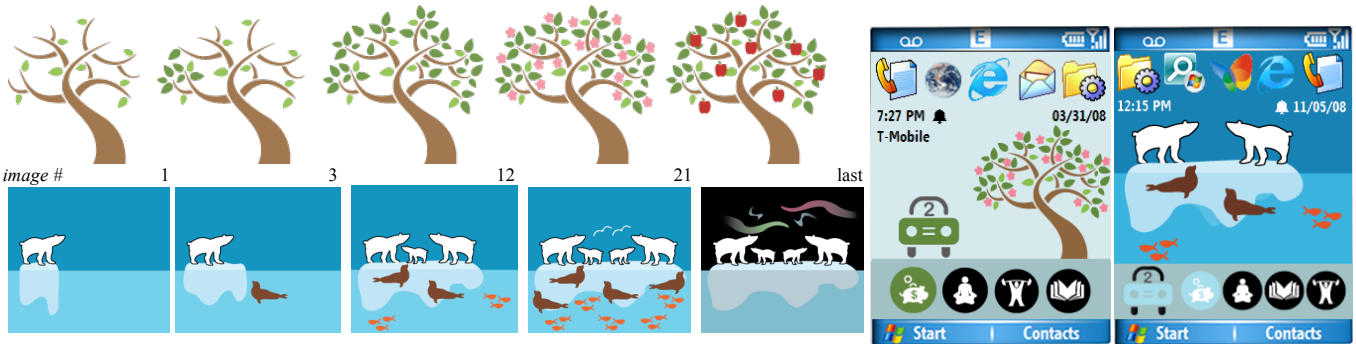

Figure 3: (top-left) A sample of images from the tree progression and **(bottom-left)** a sample of images from the polar bear progression. **(right)** Screenshots showing the graphics in context. In both examples, the user recently carpooled (as indicated by the car with the "2" in the windshield). Since carpooling saves money, the piggy bank is highlighted.

emotional attachment to a virtual polar bear could translate into concern for the environment and a tendency towards taking green action. This research paired with the results of our own formative work lead us to create two different iconic representations to reward green behavior (Figure 3).

Visual Designs

In one interface, a tree is used to indicate green transportation activity. At the start of each week, the tree is almost bare. Leaves, blossoms, and eventually apples are progressively added to the tree after each green transportation event. In the other interface, a polar bear is shown on a small iceberg. Over the week, the iceberg grows as green transportation actions are taken and the surrounding ecosystem also improves. For example, new food sources such as fish and seals appear (Image #12 in Figure 3). Both designs follow a linear sequence of images. The last image in the sequence provides a small, but engaging final reward. In the tree design, the flowers give way to fruit and in the polar bear design, the sun sets and the Aurora Borealis (Northern Lights) appears. The images never return to a previous state due to inactivity, but at the start of each week, the interface is reset to the first image in the sequence. The entire background area of the screen is filled although small parts of the images are obstructed by menus and text (Figure 1 and the right-side images in Figure 3). Due to technical limitations on Windows Mobile devices, the image transitions were not animated.

In both designs, an icon representing the most recently sensed green transportation activity is shown (*e.g.,* in the right two designs of Figure 3, the most recent activity is a "carpool"). In addition, at the bottom of the interface, four icons are shown representing other potential benefits of this activity: a piggy bank represents money savings, a person meditating represents relaxation, a weightlifter represents exercise and a book represents the opportunity to read. These four icons were chosen based on the results of our online survey, which indicated that financial savings, exercise, opportunity to do other things while traveling, and "time to think" were reasons for taking green transportation. Although one could reward users differently depending on the carbon footprint of their current transit activity we chose not to do so for simplicity (*e.g.,* walking produces zero carbon vs. carpooling, whose per person carbon footprint is dependent on the car type, number of passengers, distance traveled, etc.).

Implementation

The UbiGreen prototype was built in C# using .NET CF along with two open source tools: MyExperience [18] and ActivityDesigner [23]. UbiGreen relied on three sources for transportation data: a Mobile Sensing Platform (MSP) [8], the phone's own GSM cell signals, and the participants themselves. The MSP sensor, shown in Figure 1, is a small device about the size of a pedometer worn around the belt and contains ten sensors including a 3-axis accelerometer, a barometer, and infrared light sensor. Its onboard algorithms are able to accurately differentiate sitting, standing, walking, running and cycling activities. To avoid recording

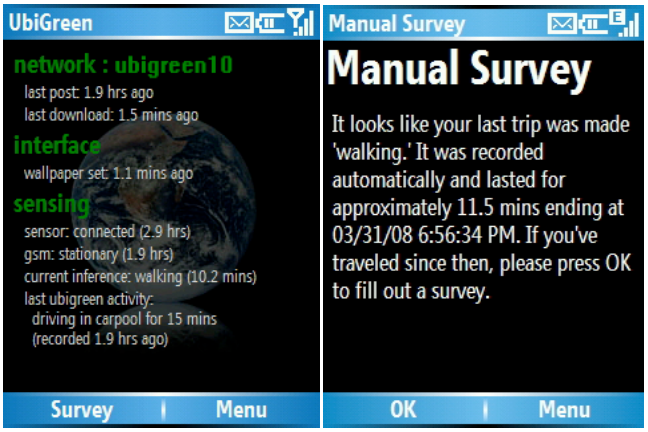

Figure 4 (left) UbiGreen's primary application screen, which informed the user about the state of the network and sensors. **(right)** To avoid redundancies in our data, self-report surveys were prefaced by a dialog informing the participant about the most recently sensed activity.

erroneously detected activities, participants did not receive credit for automatically sensed transit activities that were six minutes or less in duration.

We used GSM cell tower information similar to Sohn *et al.* [30] to infer when a participant was traveling by vehicle (car, bus, or train). We *could not* automatically distinguish between these transit modes. Consequently, in these cases, UbiGreen would trigger a two question self-report questionnaire (a "travel survey") on the mobile phone asking about the exact form of travel (*e.g.,* bus, drove alone, or carpooled). This questionnaire was only triggered after we inferred that the transportation had ceased to avoid the possibility of creating driving distractions. If the automated sensing methods failed to detect a trip, the participants could still get credit for a green transportation activity by invoking a transit survey themselves. To avoid redundancies in the data, both the manually triggered and the motion-triggered self-report surveys were prefaced by a dialog informing the user about their most recently recorded transportation activity (the right image in Figure 4)

UbiGreen was built, in part, using ActivityDesigner, which allows designers to rapidly create applications that react to data about human activities [23]. ActivityDesigner uses a combination of storyboarding and demonstration to create application behaviors. UbiGreen reported transportation activities over the Internet to ActivityDesigner, which would then calculate the next image to be displayed and send that image back to the phone. ActivityDesigner also provides an interface to playback collected field data. This allowed us to replay events sent from our participants' phones during the field study. This was useful in debugging early versions of the prototype as well as helping to monitor our participants' data as it was being generated (Figure 5).

The UbiGreen prototype also included an "information" screen that provided feedback about the real-time activity inference, the status of the Bluetooth connection to the MSP, and information about the user's mobile Internet connection (left image in Figure 4). During the first week of

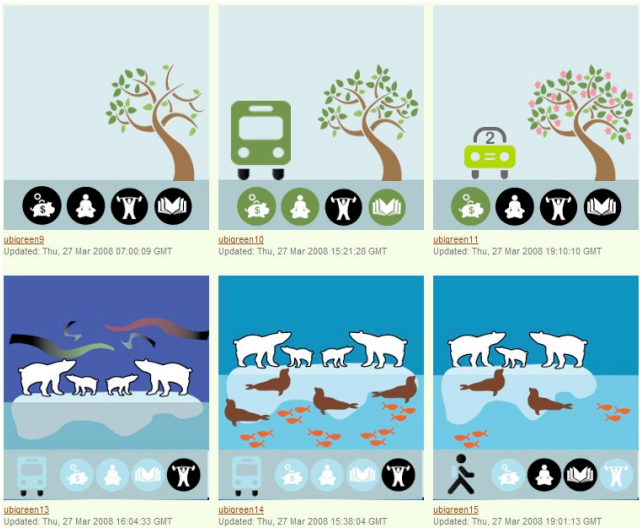

Figure 5: An auto-updating webpage allowed us to monitor the state of our participant's phones in real-time. This screenshot was taken on a Thursday during our study, five days into the week. By this point, participants had reached various stages of the image sequence (e.g., P13 on the bottom-left had reached the Aurora Borealis).

our field study (see below), participants had expressed disappointment when the sensing technology did not sense all of their trip activity or did not sense it accurately enough to earn credit. We quickly added the new information screen, which allowed participants to more easily detect whether their hardware was working and whether their current transit activity was automatically being sensed.

UBIGREEN FIELD STUDY

We used a combination of rapid iteration and field testing to get *in situ* data on the use of UbiGreen. Our goal was to compare the two visual designs and to explore issues such as social use, the most engaging aspects of our design, and responses to the changing iconic progress representations. We were also interested in exploring the viability of using semi-automatic sensing for recording transit activities.

Before we give the details of our study and results, it is important to comment on our methodology and the resulting timeline. The ability to get *in situ* data at early stages of application development is an acknowledged problem in the literature [6,9], and many researchers have engaged in tool and technique development to address these issues [5,18,23]. Because this was a design exploration, we heavily leveraged rapid development tools (MyExperience [18] and ActivityDesigner [23]) that allowed us to test our application *in situ* within only a few weeks of the start of our software development process.

That said, UbiGreen is a sophisticated technological artifact relying on external hardware sensors, mobile phone Internet connectivity, real-time inference algorithms, and backend server calculations to produce the desired application behavior. As a result of this complexity, the technology did not always function optimally during the course of the study. Some participants, for example, had trouble maintaining a stable Bluetooth connection between their mobile phone and the MSP. Others found the MSP cumbersome to wear (particularly women who did not always have a belt or belt loop for attachment). Next, we provide more details about our participants and method.

Table 1: Of the 14 participants, 7 saw the tree graphics and 7 saw the polar bear graphics. Duration ranged from 1 week to 4 weeks.

	Location	Condition	Days	Occupation
P1	Pittsburgh	Tree	27	Sales Clerk
***P2**	Pittsburgh	Tree	N/A	Attorney
P3	Pittsburgh	Tree	21	Law Enforcement
P4	Pittsburgh	Tree	9	Student
P5	Pittsburgh	Polar Bear	20	Technical/Engineering
P6	Pittsburgh	Polar Bear	12	Student
P7	Pittsburgh	Polar Bear	16	Student
P8	Seattle	Polar Bear	6	Student
P9	Seattle	Tree	42	Office Admin
P10	Seattle	Tree	19	Consultant
P11	Seattle	Tree	25	Program Manager
P13	Seattle	Polar Bear	37	Programmer
P14	Seattle	Polar Bear	30	Consultant
P15	Seattle	Polar Bear	6	Student

* P2 dropped out of the study. Her data is not included in our analysis.

Participants and Method

Participants were recruited from two major metropolitan cities, Seattle and Pittsburgh, to increase the diversity of perspectives in our resulting data. We evaluated participants' level of environmental concern using De Young's scale of 1 to 5 [12]. Our Pittsburgh participants were significantly less concerned about the environment (M=2.95, SD=0.19) than our Seattle participants (M=3.72 SD=0.22, $F[1,14]=7.0$, $p<.05$). Recruitment was done by posting to the Pittsburgh and Seattle Craigslists and using a CMU's online recruitment service. The ads stated that we were "investigating how mobile phones could be used to encourage sustainable transportation choices." We selected participants who had AT&T or T-Mobile plans, as UbiGreen required GSM cell network operators for its motion inference. Participants were paid $100-$300 depending on the length of their participation in the study.

Out of the 14 participants, 6 were from Seattle and 8 were from Pittsburgh (Table 1). The majority of participants were drawn from the working populations of both cities, although 5 were students (1 undergraduate). Half were male and half female, the average age was 26-30, and the study included two couples. Participation lasted from 1 to 4 weeks (average of 21 days, median=20).

At the beginning of the study, participants were supplied with a Cingular 2125 phone running the UbiGreen prototype, which was intended to replace their current mobile phone (we moved their SIM card for them). They also received a pager-sized MSP sensor. One participant (P2) found that the Cingular 2125 phone was incompatible with her work and thus had to drop out of the study. The participants were given an explanation of the UbiGreen prototype and training on their new phone. We also

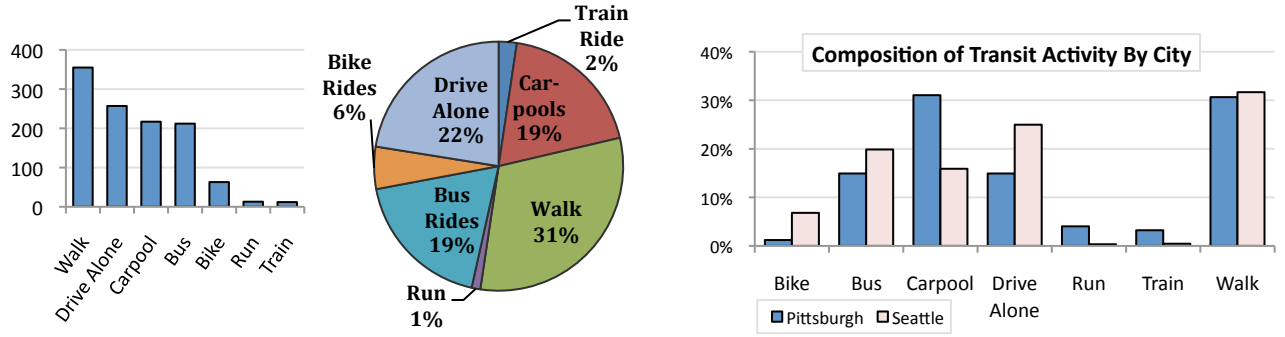

Figure 6: (left) The raw number of trips, broken down by transit mode. **(middle)** The percentage composition of all recorded transit activities. **(right)** The percentage breakdown of transit activities by city.

provided a 24 page manual and three one-page quick reference guides documenting how to use the Cingular 2125 mobile phone, the MSP, and the UbiGreen application.

We randomly assigned seven participants the polar bear visuals and seven participants the tree visuals, balanced across conditions. At the start and end of the study, participants were asked to complete a questionnaire that included relevant questions from our earlier transportation study, demographics and environmental attitudes. We also interviewed participants about their experience with the application at the end of the study.

RESULTS OF THE UBIGREEN FIELD STUDY

The goal of early-stage *in situ* deployment is to show that an application concept is feasible and to learn how it may be used and how this differs from the expectations of the researchers. We analyze our interview and transit data with respect to four issues that relate to feasibility and use: (1) the viability of using automatic sensing to detect transportation patterns; (2) qualities of our two visual designs; (3) opportunities for engagement with the issue of sustainable transportation; (4) and finally, the potential to influence behavior change.

An Overview of the Data

Our exit interview used an open-ended, semi-structured format and asked participants to describe their experiences using UbiGreen. Our transit data was logged via automatic sensing and self-report. We collected an average of 21 days of data per participant (16 days in Pittsburgh and 27 in Seattle). A "day of participation" was only counted as such if we logged at least one sensor event for that day. This was to ensure that our daily averages were not underreported. A total of over 8.4 million sensor events were logged during the study. Sensor events included GSM cell information, device usage (SMS, Internet browsing activity, phone call activity), and UbiGreen related activity data.

Transit Activity: Of the 8.4 million logged sensor events, 1,129 were travel events, 872 (77%) of which were green. This is 4.2 transportation events per day on average across participants (3.2 of which were green). The average trip length was 18 minutes (23 minutes for green trips). The number of total trips per day is in line with previous research on daily transportation behavior [19,22], which provides evidence that we were accurately recording transportation behaviors. Figure 6 presents the statistical breakdown of observed transit activities in our dataset. Like in our ESM study, the most popular form of transportation overall was "walking" accounting for 31% of the recorded trips (average length 13 minutes). The second most popular form of travel was "driving alone" (22%, 13 minutes), followed by "carpools" (19%, 19 minutes) and "bus rides" (19%, 22 minutes). In Pittsburgh, carpooling (31%) and walking (31%) were the top two most popular forms of green transportation, whereas in Seattle walking (32%) and riding the bus (20%) were the two most popular.

Data Acquisition: Transit data came from three sources: the MSP, GSM-based motion inference (which triggered a survey asking what type of vehicle the user was in), and the participant him/herself. The MSP accounted for 24% of the recorded trips (Figure 7). GSM-triggered surveys accounted for 35% of our data and manually invoked surveys accounted for the rest (41%). In all, 856 surveys were completed with a median completion time of 18 seconds.

Viability of Automatically Sensing Transit Activities

As one participant observed, UbiGreen's full potential rests upon its ability to automatically sense transportation activity, "everything should be automatically detected" (P7). Although this is technically challenging, our early prototype performed quite well at automatically sensing walking and bicycling and our GSM motion algorithms accounted for a majority of bus and carpool events.

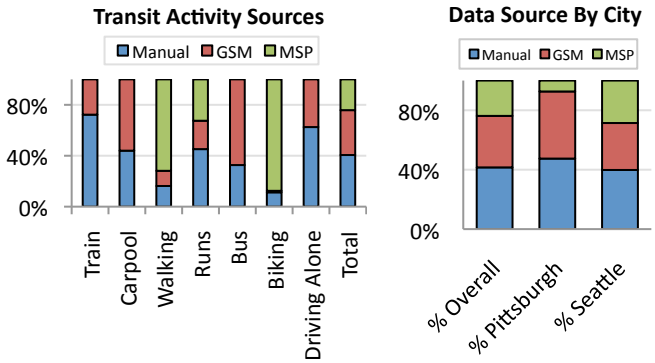

Figure 7: The source of the UbiGreen data broken down by transit activity **(left)** and city **(right).**

Still, we were hoping that the number of manually invoked surveys would be lower. One reason that they were not, we believe, is because our vehicle trip detection had a delay between the end of a trip and *inferring* that the trip had indeed ended ("I did get travel surveys after I took the bus. Sometimes it took way too long though and I would trigger the survey myself" (P13)). From interviews, most participants found that the sensing worked quite well: "The car detection was very good. Within 1 or 2 minutes after the activity was complete [I would get surveyed]" (P7).

Requiring our participants to wear an additional sensor (the MSP) was an obvious burden, "I guess the biggest annoyance for me was just having an extra piece of gear to wear" (P11). We have recently developed activity inference algorithms for the Apple iPhone using the built-in accelerometer capable of detecting walking, running, and bicycling in a laboratory setting with 98% accuracy [29].

In summary, sensing was viable but could be further automated. In addition to our iPhone inference work, we are currently investigating how GPS signals can be used to discriminate between train, bus, and driving activities.

Visual Design Qualities

Participants commented that the presence of the visual display on the background screen of the phone increased personal awareness and stimulated reflection about their transportation activities. "It really encourages you to analyze your own performance" (P8). As observed in previous studies [10], the wallpaper is frequently visible to participants as they go about their normal phone usage. One participant said, "it's omnipresent" (P9). Participants also seemed to appreciate that their "green" transportation led to a progression of the visual design shown on the phone screen. "I liked the tree because it was, to my mind, a pretty progress bar. There was enough of a clear distance between each state that I could tell the difference at a glance" (P11).

Some participants wanted more variety in the visual rewards. "The first couple of times were interesting [when the background changed]… but then it started repeating" (P13). Participants P8 and P11 both thought we could "have different stories every week … to maintain curiosity in the app," (P8) and that we, or others, could "generate their themes online and share them" (P11). Future designs could also follow non-linear storytelling patterns where users follow certain thematic arcs based on their performance (similar to a choose-your-own adventure style book, only the branching through the story is chosen automatically based on transportation behavior).

Iconic vs. Numeric Representations: Participant feedback indicated an interest in knowing *actual* carbon emissions in addition to seeing the iconic progression of the arctic ecosystem. "I would like more information about carbon emission savings" (P15). Tracking carbon savings, however, is quite challenging with current technology. As P11 noted, "if you tracked all carbon emissions or gallons saved it would be based on what kind of bus you rode in and what kind of cars people drove, it would get really complicated." Despite these challenges, it is possible to calculate an approximate impact that gives participants a sense of progress. We will explore this in our future work.

Secondary Icons: Most participants noticed the secondary icons at the bottom of the interface but few were impacted by them. "I didn't feel like they added a lot of information, like I know biking is a good form of exercise" (P11). Another participant pointed out that the secondary icons would be more interesting if "the circles filled up as you did more of those activities [over time]" (P10). We believe that highlighting secondary benefits for green transportation is still a promising area for future work, particularly when those benefits are highly personalized and highlighted in the moment (e.g., by informing them that a bus route is actually faster than driving or that bicycling to work would save X dollars over the month).

Negative Imagery: Some participants were keen to mention using both positive and negative imagery depending on performance, "I think negative reinforcement would also be good. I think maybe my polar bear should drown if I am bad" (P14). Another participant was even more macabre. He stated that if you were really bad, "maybe penguins should show floating dead-up in the water." (P15). It may be worth pursuing future designs that include both positive and negative reinforcement—leaves falling from the tree, for example, when a user drives excessively. These options could then be evaluated more systematically for impact.

In summary, our visual design was effective and *present*, but participants asked us to show more detailed information (such as more varied stories; actual carbon savings; tracking secondary benefits numerically; and so on).

Opportunities for Engagement

Although in a field study of this length, novelty likely plays a strong role in application usage levels, it is still interesting to highlight aspects of our design that participants specifically mentioned as motivating. Two unexpected themes arose—one was the idea of the application as a real-life game and the other was the anticipation and curiosity inherent in moving through the sequence of images.

UbiGreen as a real-life game: Although we did not describe UbiGreen as a game to our participants, many perceived it as one. In interviews and in our freeform post-study survey data, participants would use game-like metaphors when describing the application. For example, participants mentioned that engaging in green transit behaviors earned "points" and making it to the last screen was the "final level." One participant even complained that when a trip hadn't been automatically recorded, "I felt like I was being cheated out of my points" (P15).

Because so many participants conceptualized UbiGreen as a game, they considered opportunities to "cheat" the system to be problems. One participant described UbiGreen's method of "earning points" as potentially flawed, "I don't like incentives for getting points artificially by taking unnecessary trips… like trying to beat your own score by taking two more trips just to earn points." (P11). This

participant was worried that UbiGreen might encourage people to take *more* trips simply to earn more points (some green trips could lead to more emissions than no trip at all).

Future designs that incorporate a more overt gaming model could mitigate these effects by rewarding "more points" for zero-carbon trips such as bicycling and walking. The application could also reward the user for taking fewer trips from week to week. Finally, although carbon tracking is still an active form of research [35], a progress bar (or some other visual indicator) could be used to reveal total carbon emissions for the week.

Anticipation and Curiosity: We did not disclose the image sequence or "final image" to participants ahead of time. This created a sense of anticipation and curiosity. P10 commented "I liked that we didn't know what it was going to do. Like when your phone turned from leaves into flowers and then apples." Similarly, P14 said "I wasn't sure if there was anything else [after the Northern Lights], so I kept going." As previously mentioned, designers could take advantage of this by offering new weekly themes or themes that continue progressing through a story over time.

Social Sharing of Transportation Activity: Although our design was not inherently social, nearly all of our participants commented that the graphics on their phone's background display became conversation starters at work and at home. More interestingly, however, some co-workers seemed to take an interest in participants' progress "Some people at work knew about the polar bear and every day they asked me about it. 'Did you get a seal today?'" (P14). Similarly, both of the couples that participated in the study developed a sense of competition. "There was a competition with P15 like I mentioned; he would always ask about my phone" (P14). "Yah, P14 started a day before me so that I was always one day behind her" (P15). We believe that exploring how social motivators like competition can be used to influence transportation behaviors is a rich, open area of future research [28].

Real Time Recommendations: In the UbiGreen field study exit survey, we asked participants what could help them to make more green trips. The top two things they selected were reliable transportation (79%) and financial incentives (71%). However, more knowledge about alternatives (56%) also received a high rating. Specifically, P13 mentioned that one improvement to UbiGreen could be a recommendation system that suggests alternative forms of transportation based on your personal trip history. In cities like Seattle, where the public transit system publishes real time data about bus locations using GPS, these recommendations could be very specific. Such a system could even incorporate shared commute data by other UbiGreen users—"42% of the people who live in your neighborhood and work in Capitol Hill take the bus."

In summary, users encouraged us to do more with the game-like properties of UbiGreen and to factor in real time data about friends and/or transportation options, time, cost and CO_2 savings. This would also address the issues of convenience raised in our online survey. In some cases, it may be that a green form of transit is actually faster than driving (e.g., buses can circumvent traffic by using the high-occupancy vehicle lanes).

Potential for Behavior Change

Our formative work showed that participants would value feedback about their transportation choices and identified forms of feedback that might help to support and sustain greener transportation choices. Our field study clearly demonstrated the viability of our concept, to which participants responded positively on many fronts described above. In fact, 7 of the 13 participants continued using the software beyond the planned end of the study. Participants talked about gaming and points, and expressed concern about cheating, all indications that they were engaged by the system. While an early-stage study like this cannot reasonably be expected to *confirm* that behavior change occurred, our qualitative results indicate that participants were engaged in the application (a prerequisite for behavior change) and did start new behaviors.

At the end of the study we asked whether participants felt that UbiGreen had encouraged them to travel in a more eco-friendly way and what they did this week to be more green. In open ended responses on our exit questionnaire, three participants gave specific answers about changes they had made. P3 wrote "I've been carpooling to work and walking to my familys [sic] houses because they are close enough to do so, though before i [sic] would usually just hop in my car." P9: "I've tried to carpool more to go to church (I go to church more than once a week)." P10 reported "…learning to ride a bicycle more confidently." Two of these (P3 and P9) were the least green participants involved in our study. Most other participants told us things like "I feel I already travel in a relatively eco-friendly way and the study did not change that" (P15), a reflection of the fact that most of our participants were already very green and had lifestyles amenable to not driving (such as living and working in an urban area or living next to a bus stop). A common request amongst our participants was the ability to compare their current week's performance with previous weeks. This also implies an interest in understanding how their own behavior changes over time.

Still, some participants felt that the visual feedback was not enough to change their transportation habits. For example, P6 mentioned that "It definitely keeps you more aware of it [transportation habits] every single day. You use your phone every single day so you know… but I'm not sure if being aware of it changes your habits." Only a longer and more controlled study can truly answer this question.

CONCLUSION & FUTURE WORK

In this paper, we presented results from a set of formative studies exploring individual transportation, which led to the development of the UbiGreen Transportation Display, a mobile application prototype that semi-automatically senses and reveals information about transportation behavior. We described the results of a 3-week field study of the use of

our prototype in two distinct U.S. cities. Our contributions are a system that semi-automatically tracks transportation behaviors, a visual design capable of engaging users in the goal of increasing green transportation, and implications for the design of future green applications.

Ultimately, we plan to conduct a more extensive field study with a redesigned application running on the Apple iPhone, which will also displays approximate carbon savings information. This eliminates the need for an MSP and will make it easier to investigate systematic effects over longer study periods. We also plan to explore the value of sharing application data among social groups by leveraging a social environmental website, StepGreen [27]. This will allow us to explore the unconstrained use of the system with more people over longer periods of time, and to learn about the value of sharing application data among social groups.

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