Trustworthy By Design

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ABSTRACT
Driven by changes in working practices and technology trends, organizations are increasingly reliant on mobile workers and the data they capture. However, while significant work has been carried out on increasing the usability of mobile devices and applications, little attention has been paid to the quality of data captured by mobile workers. If this data is inaccurate or untrustworthy, serious consequences can ensue. In this paper we study a system targeted at mobile workers in the highways sector that is deliberately designed to increase the accuracy and trustworthiness of the data collected. The resulting Inspections application has been very positively received by workers and we present lessons that we believe can be applied to other applications of this type.

Author Keywords
Trust, data collection, mobile computing, mobile work, highways maintenance, ethnography

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms
Human Factors; Design; Measurement.

INTRODUCTION
While the average citizen rarely considers such issues, the drains (or gullies) that keep our streets from flooding accumulate silt and debris over time, requiring regular cleaning to maintain safe conditions. Collecting accurate information on these gullies is important to improve maintenance operations and to meet legislative requirements (e.g. [21]), but it is also a difficult data management problem for the highways contractors involved. Firstly, these contractors must locate the gullies they are responsible for, which requires collection of these assets over a large area. Secondly, contractors have to keep track of which are cleaned, when, and when they might need to be cleaned again.

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Traditionally, paper records were used to record this information, but increasingly mobile tools have been introduced to help with data capture. First generation solutions recorded instances of gully cleaning through linking of GPS and sensors that detected when a maintenance truck was actively cleaning. Second generation solutions added extra buttons that allowed operators to input additional relevant information, e.g. 'Gully is blocked'. More recently, third generation mobile management tools have emerged for the collection of asset data histories and integration with multiple forms of asset data.

Our interest for this paper is not so much to explore the ins and outs of gully collection — as fascinating as we have grown to think it is — but rather to explore the elements of design that enable accurate, and above this, *trusted* data collection in this domain, with a view toward applying these more generally to other mobile data capture domains. The issue of trust in data collected in the field is of critical importance to many organizations. For example, in the context of gullies, accurate data can significantly improve the efficiency and effectiveness of maintenance — potentially helping to avert serious flooding in extreme cases. Additionally, if more mundanely, accurate data can reduce the need for, and therefore the cost of, maintenance by some 80 percent according to recent estimates. Trusted data is also critical in a wide range of domains such as health, policing, environmental monitoring, surveying and disaster management where inaccurate or untrustworthy data from the field can have serious consequences.

However, verifying data collected in such domains, is challenging — how do you check the accuracy of the data collected without incurring significant extra cost? Indeed, in many cases post-hoc verification of data collected in the field is simply not possible. For example, in health scenarios there is almost certainly no way to go back and check that the initial data captured on a patient at the scene was accurate. Similarly, for gullies, knowing when they became blocked relative to an inspection is a difficult task. As a result, a key challenge is to collect, at the outset, accurate data in which organizations can place significant trust. This trusted data, as we will show, links with a range of other important qualities to do with successful completion and management of work, and can change for the better the way business process is organized.

In this paper, we describe the development of a third generation mobile data collection system (Inspections), which has been built and deployed since May, 2011, in a total of five

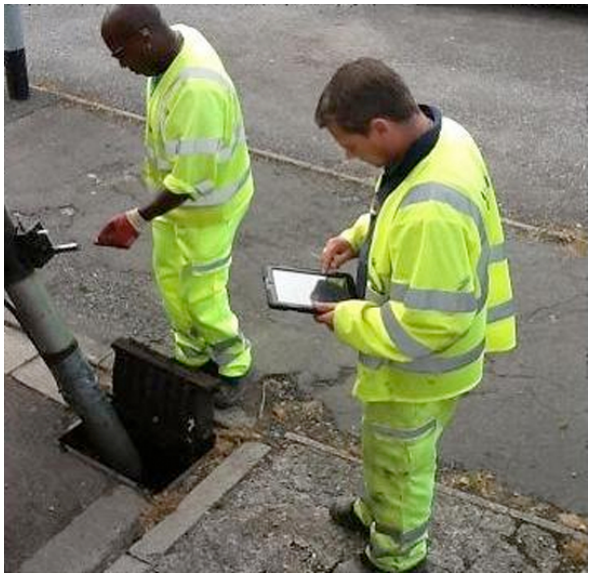

Figure 1. Using the iPad app on site.

locations. We begin by describing the extensive ethnographic fieldwork that inspired our focus on trust and informed the requirements of our system design. Next, we describe the system features in terms of how they respond to the particularities of gully maintenance work, and how these features are intended to contribute toward accurate data. Finally, we use trust as an analytical lens for reflecting on lessons learned from our experience in creating a successful mobile asset collection system, and from this, develop several principles of successful system design that can be applied to a range of domains. We hope to show that trust is not easily retrofitted into systems, but that when trust is a clear design aim throughout the development process, it can be successfully engineered by carefully attending to requirements of the application domain whilst exploring the unique affordances of mobile technology.

RELATED WORK AND NOVELTY

Trust is a familiar if not well-developed concept in the CSCW literature, particularly as it relates to the difficulties of trust surrounding remote work activities. Although precedents for such inquiry exist (e.g. [18, 19, 34, 35]), recent mobile technologies innovation presents new opportunities for investigation.

We adopt a definition of trust fitting with [13], i.e. trust is a subjective assessment of reliability, and we explore trust specifically as it relates to 'trusted data' in the context of developing quality systems. Our research engages with a multidisciplinary body of trust literature that has resulted in a range of competing understandings and theoretical frameworks (e.g. [3, 4, 14, 19, 25, 43, 46]). In contrast to these theoretical angles on trust, we approach the subject from a practical perspective, exploring the concept as an explicit design goal of technological systems that can produce tangible benefits to organizations.

The principle novelty of our work is exploring trust as a complex and emergent phenomenon resulting from design decisions related, but not limited to, the goal of producing *accurate data*. Furthermore, as there is very little research in the way of broadly applicable principles for developing systems that work, whether or not they pertain to the role of trust in doing so, this paper offers a unique contribution to the vast community of researchers who develop such systems.

Given our chosen focus on mobile solutions for producing accurate data as a prerequisite for trusted data, it is worth contextualizing our contribution within not only trust literature, but also within literature related to the challenge of accurate mobile data capture. Many previous studies related to accurate data capture report on the use of cheap and relatively basic mobile phones, such as can be deployed in resource-poor scenarios (e.g. healthcare [26, 28] and business [36] in the developing world). In recent years there has been an increased interest in smartphones for data capture, though many of these studies focus on data capture for purposes of crowdsourcing and participatory sensing [6, 20], experience capture [41], feedback [12], etc., in which accuracy and trust play a less critical role. Most data collection of governmental and/or business importance (such as in our chosen highways maintenance domain) has historically been done using Windows Mobile data collection devices (DCDs), such as those we are familiar signing when receiving a package delivery. Our system, however, leverages the affordances of commodity consumer hardware, i.e. smartphones, for generating accurate data collection.

While we have made clear that our interest is primarily but not always in highways maintenance work itself, there is little existing CSCW work in this area to draw from in terms of design insights for a data collection system in this domain. Liu et al's [22] study of public service workers in Seattle examines a number of different public service workers with only a marginal interest in road maintenance. And whilst [16] does concern itself with roads, the emphasis is entirely on safety and document work rather than standard, manual maintenance work. Our understanding of design issues related to this domain, therefore, result directly from our own ethnographic research, detailed below.

FIELDWORK

In this section we document some of the empirical issues about trust — how trust is manifested in various observed interactions in the workplace — by presenting some of the ethnographic findings from our fieldwork on aspects of highway maintenance and repair. The fieldwork was not only helpful for generating insight into lack of trust, but also how this lack of trust was remedied in order to accomplish work as a practical everyday matter. In the process, is it possible to identify the important role of trust in such organizational work, how people 'perform' trust, how it is instantiated in various paper and electronic documents and how it enters into everyday work through aspects of planning, coordination and awareness (cf. [14]). We include findings from the wider context of highways maintenance and repair, within which sit gully maintenance activities, to provide necessary context for

what has ultimately informed the design of our gully intervention. After all, this context is the basis of our inspiration for focusing on trust. Having drawn out some insights from general highways maintenance work, we focus specifically on the nature of gully maintenance work and elicit further specific insights.

Methods

Our fieldwork involved informal, semi-structured interviewing (asking about work and trust incidents) and periods of observation (shadowing highways inspectors or highways maintenance gangs as they went about their everyday work). The (ongoing) fieldwork reported here was carried out by two ethnographers at seven different sites in the UK over the course of a year and amounted to approximately 70 interviews (of differing durations) and approximately three months worth of observation. Interviews were transcribed and fieldnotes typed up and examined for broad, recurring themes which acted not as precursors to the development of theory but as broad requirements for design. Of particular interest was the detailed explication of the work of the highways inspectors (employed by the council) and road maintenance and gully clearance gangs (employed by the contractor).

We look to our fieldwork to reveal instances of how trust is woven into the fabric of everyday organizational life — or not; instances of how trust is achieved in everyday work — or not; and what sort of things produce trust and trustability — or distrust and suspicion. In our fieldwork studies we paid attention to the social process of trust production, to specify the social mechanisms which generate trust and to examine and document the various ways in which trust is woven into the fabric of everyday organizational life as part of the taken for granted moral order [15].

Behind this work is the idea that electronic devices of various kinds might be used to improve the work process, so our interest in understanding the details of everyday work and how trust is manifested is as a precursor to design — to move from a current paper based system to an electronic system of some kind. Our exploration of issues of trust in road maintenance began by identifying several different stakeholders or parties (or 'users') between whom and for whom issues of trust arise. One major stakeholder is the public who obviously use the roads. The 'council' whose staff initiate and inspect (and sometimes carry out) the work and who are most likely to face complaints from the public is another stakeholder. Our final stakeholder is the contractor who carries out the road maintenance work. In the section to follow, we describe these roles in the context of how they contribute toward an overall organizational workflow, and how this workflow reveals potential trust issues relevant to the design of a technological intervention.

Trust issues within highways maintenance work

Defects needing repair or maintenance are identified via two mechanisms: council highways inspectors locate them during the course of their inspections routines, or members of the public call in with complaints. When reported by the public, an inspector will have to go out and examine it to determine that it is, in fact, a defect and decide what action is needed to remedy it. At the moment, this is necessary because reports are made over the phone and are not accompanied by photographic evidence and a time/location stamp, which might serve to verify these claims.

Defects are then logged on the local council's asset management system and allocated a due date according to the level of danger it poses to the public. Once receiving a list of defects, contractors are expected to complete them by their due date. Schedulers, who are responsible for allocating jobs to their team of gangs, reported suspecting the council of "artificially escalating" jobs to force the contractors to work faster. What councils fail to realize, they argue, is that escalating jobs reduces overall efficiency, requiring gangs to run around like "headless chickens". There is a perception that public pressure, and a greater role for the public, is a driver of inefficient scheduling: *"You're then empowering people that don't really know a lot about the job. And then everyone wants everything done outside their own house... People that are actually paid to make decisions don't make decisions"* (Scheduler).

The contractor's highway maintenance gangs are given a list of jobs to complete (either for the week or for the day). While onsite, gangs will typically be visited every day by their own supervisor — who checks for compliance with safety regulations and ensures work is being carried out according to plan — as well as by a council inspector, who they will have to phone to get permission for deviations from the schedule. Throughout the day, gangs' locations may be monitored via tracking devices: a feature that allows monitoring in the absence of trust.

What seems especially notable in highway maintenance work, an observably physically demanding job, is the sheer amount of paperwork involved. When a gang arrives onsite, they go up and down the street looking for the markings left by the inspector. They find the job, and begin filling out paperwork:

- Two Minute Risk Assessment (mandatory, all): These need to be done for each job (each street).
- Site Briefing (mandatory, per day): These need to be signed by all gangers (i.e. each member of the gang), one per day. They have to list the kind of Traffic Management™ they will use, referring to the diagram numbers in the TM book.
- Traffic Management Audit (mandatory, per judgment): Usually traffic management audits are completed by Inspectors. But sometimes the gang will arrive onsite and feel they cannot proceed without contacting the Supervisor to get him to come to site to complete a traffic management audit.
- Permit to dig (mandatory, if digging): This is completed by the Supervisor. If a crew finds unexpectedly that they need to dig, they will have to contact the Supervisor, who will then have to deliver it to site.

- Ordering materials (as needed): If for some reason they have run out of materials, the gang will have to contact the Supervisor to get an order number for new materials.

Then they complete the work and fill out more paperwork:

- Record sheet (mandatory, all): Gangs need to record who the operatives were, weather conditions, the actual works carried out (and how they may have differed from the job description), time on and off site, plant used, material used, and whether it was a temporary or permanent fix.

Completed work is reported back to the council, along with all of this documentation. In some cases, the council will then send an inspector out to verify the completion of these jobs before removing them from the system. The public is perceived as aggressively litigious, and management ensures the gangs spend time documenting their work: *"I'd rather have them not do as much work in the day than have a 15 grand's worth insurance claim."* Contractors understand that the public is not always aware of all the repairs that have been made, and were keen to get a system to enable them to *"actually go to a member of the public if they like and say, 'Look, this is what we've done."'*

This lack of trust and the apparent need to continually inspect work has major implications for the efficiency of highways maintenance. As a result, it has major cost implications, resulting in an estimated overspend of tens of millions of pounds per year, or approximately 30% of total expenditure (by our calculations). As schedulers and gangers themselves have noted, efficiency is not easily increased through top down measures (e.g. escalating jobs), and often result in a cycle of distrust. By not trusting the contractor to get work done efficiently, the council ends up decreasing the contractors' efficiency; this then decreases the council's trust in the contractor's ability to deliver jobs on time. It has also apparently decreased contractors' trust in the council. Like 'the boy who cried wolf', contractors may over time be less inclined to take seriously the deadlines set by the council, potentially increasing the chance of instances of unreliability with more damaging consequences to accrued trust. In contrast, were the council to trust contractors, efficiency would result as a natural consequence of empowering people who are best able to make decisions, thereby catalyzing a virtuous circle of trust. The design challenge, it would seem, is providing those with managerial control (e.g. the council over schedulers, supervisors over gangers) a *reason* to place this trust in workers.

The emphasis on continuing and continual audit [30, 31, 40], the importance of recording activity, and the importance of paperwork as a permanent record of that activity, points to further interesting issues regarding trust (and distrust). Our analysis reveals that 'trust' resides in these different paper documents in various ways. On a basic level, documents handle information; information about defects, various assets, or activity occurring around these assets (e.g. when a road was last checked). Trust, here, relies on data being accurate or checkable in various ways. Documents seem to enable trust in part by creating a 'stratified trace' of the orderliness of activities. A document provides history, in this case of a stretch of road; but that historical record is only trustworthy as a result of lower level instantiations of trust: trust in location, trust in the represented order of events, and so on. A document further acts as a coordinating device, and trust placed in that document can be translated into an appropriate organizational formulation — what needs to be done, by whom and when it needs to be done by.

These insights reveal several important trust considerations, which served to guide our initial thoughts about development of a mobile data capture system intended to increase trust between various parties:

- *Supporting the identification and persistent storage of evidence.* This evidence is the kind of evidence that people use to make reliability assessments — a key metacognition in the formulation of trust.
- *Understanding and graphing the complexity of interdependent processes and relationships to deliver on organizational assertions.* Understanding processes provides the context that is necessary for individuals to evaluate the equitability of the process, identify worker expertise and competencies in which trust might be placed, and share relevant information for successful completion of work.
- *Providing trust warnings in the form of data visualizations and inline user interfaces to involved stakeholders.* Real-time evidence capture will be used to prepare people for possible failures to deliver on expectations, mitigating the erosion of trust between parties.
- *Visualizing the impact of individuals' actions throughout the system and process.* This will invoke social scripts, which will make people more accountable to themselves and to one another. In turn, this accountability will likely lead to greater integrity of individuals. Furthermore, this visual feedback is necessary to continually reinforce this integrity. Ultimately, this may provide one mechanism for generating a *reason* to trust.

Development of our mobile data capture system for gully maintenance was inspired and guided by this understanding of trust in the context of the highways maintenance sector, which we formulated over the course of approximately two years of ethnographic research as part of the development of a separate but related works orders management system. Further fieldwork was undertaken over the course of several months (by two ethnographers) to explore the particularities of gully cleaning.

Unique aspects of gully maintenance

The core responsibility of gully gangs is to ensure that water is able to drain into and flow through gullies. In addition to cleaning gullies, gangers must also repair damaged lids. In instances when they cannot repair a lid with the materials they have on their trucks (e.g. if they run out of a particular type of lid), they must generate a work order for another crew to complete at a later date. The overall workflow of the process is as follows. A gang is given a list of streets requiring gully maintenance. They go up and down each of these streets,

stopping at each accessible gully. A ganger lifts a lid off of the gully, blasts water down the gully to break up any sediment, sucks up the liquid to remove the silt, and runs water through to check whether it is flowing properly. This process is repeated as needed until it is flowing properly. Then the gangers get back in the truck and drive up to the next gully and clean/repair it. They do as many gullies as they can do in a given day. If they are not on track to complete all of the gullies within a given timeframe as agreed by the council and contractor, additional gangs may be brought on to complete the work.

In addition to the trust issues endemic to highways maintenance work generally, we were able to derive additional trust issues worth considering in the context of gully maintenance. The most noticeable feature of this particular work is the way in which decision making opportunities are effectively designed out of the process. Gangers work to a cyclical cleaning regimen, which they follow blindly. While this approach does enable thorough, systematic cleaning of the council's gullies, it is highly inefficient, since many gullies do not actually require cleaning. Furthermore, and in terms of trust, while it is easy to fall short of expectations, it is not particularly easy to exceed expectations. Whereas a pothole repair gang might increase productivity by attending to jobs in an order which reduces travel time, a gully gang cannot devise any intelligent solution for increasing productivity. This creates a scenario in which trust is far more easily lost than gained.

Secondly, in contrast to reactive repair work like pothole filling, gangers do not record each gully as they clean it. Rather, they record the completion of a portion of road, which may contain many gullies. This means that the council does not have a history of maintenance activity for each gully (in many cases, they do not even know the number of gullies in their district). While it may seem unnecessary to trace activity for individual gullies, this information could be leveraged toward the development of more efficient maintenance routines. Furthermore, it would allow contractors to attend to problem gullies, such as the ones filled to the lid and sprouting plant life, whether or not they had met their legal obligation to clean it every six months. This would cut down on the number of complaints from the public, and help generate confidence that gangers can be trusted to do a good job.

The ethnographic fieldwork we conducted for gullies was intended not only to reveal further insight into trust, but also, more fundamentally, to capture requirements for our system design. The two ethnographers produced write-ups for the software development team that included minute details of carrying out gully maintenance work that must be designed for to ensure system success. These requirements, along with the understanding of trust we had developed up to this point, informed the design of our mobile data capture system, Inspections, which we describe in the next section.

THE SYSTEM

Overview

The mobile management tool, Inspections, that we have designed and studied allows mobile workers in the field to collect and manipulate a wide range of assets and to send this data back to a central office for processing and review. A demonstration of the system can be found at `http://www.intouch-ltd.com/gully_cleaning.asp`. The requirements for the system were derived from an extensive capture process involving several ethnographic visits, interviews, evaluation of several prototypes and analysis of past experiences with prior systems.

Figure 2. Locating gullies on the iPad.

The system is structured as a web application for office workers and an iOS based mobile client for the workers in the field. While the system allows the collection of different types of highways asset, in this study we have focused exclusively on the mobile component and its use as a tool for collecting gully data. While many systems designed for mobile workers rely on ruggedized hardware designed for niche markets, we have found that commodity consumer hardware (specifically iPhones) are able to function effectively in this environment with suitable cases.

The mobile application can be used for two purposes: conducting an initial survey of the state of gullies and supporting subsequent cleaning and maintenance of gullies.

Gully Collection

The mobile application initially allows users to accurately map assets. We have found that GPS provides adequate coarse grained positioning but in many cases users need to be able to reposition assets (e.g. in instances when they cannot position the device directly over the asset due to an obstruction, such as a parked vehicle), and this is supported by the application. In addition to position, users capture a range of data about the state of the gully including reports of any damage and a photograph of the current state of the gully. Once assets have been plotted on the map, users are able to see the data that they have just entered on their device — helping them place assets relative to each other providing visual conformation that asset data has been accurately recorded. As many assets occur in groups (e.g. several traffic lights might be sited at the same junction) the system enables users to enter data on multiple assets as a group.

Figure 3. iPhone use in the field.

Figure 4. Recollection using the iPhone app (detail).

Gully Re-Inspection and Maintenance

Once an initial data set has been collected, the application can be used on a daily basis by maintenance workers to update information on individual assets. This support for re-inspections, which is the principle advance from second to third generation asset collection, enables users to recollect that same asset again and again, building a history of data against that asset. Users can also change any data that is incorrect by doing a recollection. They do not have to create a new inspection every time; data is pulled forward — some of which is immutable, some mutable, some blank, as appropriate (see Figure 4). In particular, the system allows users to reposition assets. This is important as assets may have been located in the wrong position during an initial inspection.

While inspection and re-inspection of assets is important, the true value of the system comes from its ability to provide maintenance operatives in the field with tools to view collected data in order to inform their maintenance decisions. Given the very large number of gullies that need to be collected (in excess of 200,000 is not uncommon) the system provides a sophisticated set of filters to enable viewers to hide irrelevant data from view. This combination of filtering and access to all the past data on local assets can transform the way highways maintenance operations are performed. In particular, it provides empowerment to the users, allowing them to be in control of their work and to choose how to carry it out, e.g. inspectors can choose to see all the gullies that they did not have time to check last time.

Visibility of past cleaning information can also be used to support a business process switch from a cyclic cleaning regime to an *intelligent* cleaning regime, whereby decisions about which gullies need cleaning can be predicted based on historical patterns. Crucially, proactive management is not done by managers in the office, but can be done by the workers themselves in the field. This is supported both by enabling mobile workers to access asset history on their devices and by allowing workers to add 'frequency prediction' information to an asset. More specifically, when a gully is collected/cleaned the user can select from a drop down menu how soon they think it will need to be cleaned again.

ANALYSIS

User feedback indicates that Inspections is a system that works, and works well. Both the gully crews and management had quickly learned to use and appreciate the various features of the system and, importantly, indicated that they both trusted and liked it. Some of this success can be put down to the extensive ethnographic research done up front and careful planning to attend to the needs highlighted by this research through iterative ethnographic/development cycles throughout. For example, users appreciated the way the system closely followed existing procedures for gully cleaning, the way in which it speeded up the work process, and the use of photographs to document, to provide a trustable record of, their work. Much of this success, however, we put down to serendipity, in the sense that we recognize the dynamic complexity of introducing a system into any organization; yet in hindsight we can glean a fair understanding of the design elements (planned or not) that contribute to the system's success.

There are particularities of the highways maintenance sector, and gully cleaning within that, that entail specific design constraints and UI solutions to match these constraints. In addition, there are design considerations that pertain to our chosen device and platform (Apple/iOS). While we could extract lessons from our experience with Inspections that apply to these particularities, we suggest that it would be of greater benefit to the community to distill more generalizable lessons

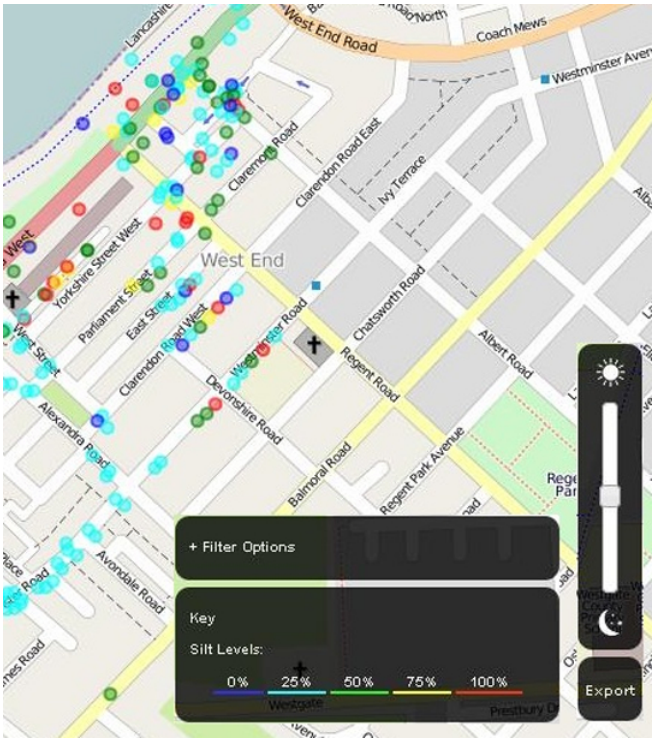

Figure 5. Filtering collected assets on the web portal (detail).

with broad applicability to other problem spaces. To do so, we begin with a brief discussion of the affordances of our mobile data capture system and explore how these affect *empowerment*. Next we explore additional characteristics that contribute to system success. Finally, we conclude by discussing how all of these factors contribute toward trusted data.

Organizational affordances

When designing mobile solutions, one issue affecting uptake relates to the desirability of the mobile devices themselves, and the 'sexiness' of the UI. Understanding the characteristics that engender this desirability has been explored by others (e.g. [27]), and while we are convinced that this desirability played an important role in getting users to want to use the system and to take good care of their devices, we cannot claim a great deal of credit for these successes. We can, however, claim credit for having designed a system that allows the easy and reliable capture of all necessary information — and all otherwise *useful* data — which can then be utilized in developing process improvements within highways maintenance.

At a minimum, mobile solutions must allow the collection of the same data as the paper-based systems they replace. However, they can offer so much more, in terms of generating what we would call a 'quality system'. Some of the affordances Inspections capitalizes on include the following:

- *'Wizarding':* Collection and recollection both force the user to enter all mandatory data before they are able to move on.
- *Pinpointing location:* The device's inbuilt GPS is used to generate initial locations (accurate to within 2m), but these can be further refined by allowing the user to adjust that location to give pinpoint accuracy (to within 50cm).
- *Filtering data:* Users can not only view relevant data, but also hide irrelevant data.
- *Gathering asset histories:* The system ties data collection to a specific asset, and users can continue to add information to this same asset over time.

These examples serve to highlight the distinct 'functional affordances' [17] of the technology we employed in comparison to traditional paper-based management systems.

But just as a quality system does not result inevitably from developing on quality devices, it also does not arise from these added affordances alone (though this should in no way undermine the UI work that went into making these elements function as well as they do). As [44] notes, introducing a system into an organization entails a complex emergent dynamic between the system and what that system enables users within the organization to do. "These factors," the authors write, "go beyond basic functionality, dialogue and representations of a technology and encompass organization culture, changes in organizations, users' identity and power differences and their emotional, symbolic and functional values related to the technology". We argue below that Inspections makes possible several further organizational-level affordances: 1) it empowers crews to engage their creative intelligence; 2) it empowers the organization as a whole to shift to an intelligent management model; and 3) this empowerment is enabled by — and in turn perpetuates — the fostering of *trust* throughout the different levels of the organization.

Empowerment

The term 'empowerment' has been defined in various ways and applied to various 'levels'. At the individual level, there are two commonalities across competing definitions which are particularly relevant to our experience with Inspections: 1) people have natural strengths that they can use and build upon [45]; 2) people understand their own needs better than anyone else does, and should have the power to act on them [8] (cf. [23]). At the organizational level, researchers differentiate between 'empowering organizations' and 'empowered organizations': the former serves to foster psychological empowerment for individuals within that organization or otherwise influenced by that organization [47]; whereas the latter ('empowered') are those that "influence the larger systems of which they are a part" [29], increasing their own effectiveness in achieving goals. Below we describe how Inspections empowers at both of these levels.

Crew empowerment

In previous gully collection (both paper based and first/second generation gully systems), workers were expected to stick to a cleaning routine that ensured compliance with governmental requirements. This did not accommodate the fact that gullies need more or less frequent cleaning depending on a range of environmental factors, resulting in some gullies being cleaned unnecessarily, or more

problematically, some gullies not being cleaned as often as needed. Meanwhile, the cleaners themselves had relevant, local knowledge about these gullies that was not being utilized.

Our goal with Inspections was to design a system to enable individual workers to engage their creative capabilities in exercising greater control over their daily work. To this end, Inspections makes use of crews' previously untapped knowledge by asking them to predict the frequency of cleaning required for each gully. But further, it enables them to act on this creatively and independently, giving them the power to craft their maintenance schedules in accordance with their expertise, and being able to make these decisions by utilizing relevant data from their devices in the field (i.e. without needing scheduling input from supervisors). As a result, workers tell us they like using the system, which we think reflects the psychological benefits typically associated with empowerment, including increased job satisfaction [10, 37, 42]. And this makes intuitive sense: rather than feeling like robots or slaves to inflexible routines, workers can feel competent and engaged, and contribute toward making their cleaning efforts more successful.

Organizational empowerment

A key goal of the target organization (the highways contractors and the maintenance crews) is to maintain safe road conditions. In the absence of tools such as Inspections, local councils' solution to this rather complex management problem was to commit contractors to a related though somewhat different goal: to clean each gully within a given timeframe (whether or not it actually needed cleaning). As a result, organizational efficiency was bounded by the number of gullies in their area and the number of gullies their workforce was physically capable of cleaning per day. Within these constraints, the most obvious way to increase efficiency was to ask the crews to work harder, resulting in inevitable tensions.

Inspections, on the other hand, enables the organization to increase efficiency through strategic means while enabling the workforce to operate at a safe, healthy, *realistic* pace — with the added benefit that this is conducive to data accuracy. Ultimately, this has revolutionized these organizations, freeing them from a blind, cyclical cleaning regimen and enabling them to proactively target the gullies that are likely to cause unsafe road conditions. Efficiency and quality improvements both result from the fact that the system allows inspectors, crews, and management to work together in deciding which work they do *not* need to do, so that they can devote resources where they are most needed.

Successful characteristics

With empowerment we have isolated a fairly high-level contributor to success. It is important to recognize that this empowerment is itself enabled by lower-level successes; and that certain characteristics of the design contribute in other ways toward producing a successful system. We highlight three such characteristics that have played a particularly important role in Inspections' success.

Performance

In situations where the data entry is an onerous process, users may be unwilling to correct errors by re-entering data. We have witnessed, in contrast, the benefits that come with using high-performing devices. Inspections forces users to fill in all mandatory data fields, but because the device (and the UI decisions we have made) make doing so a very quick process, users are able to complete a collection or recollection quickly, knowing that they can recollect again just as quickly if they need to make corrections. Workers are more likely, as a result, to correct mistakes that they may have made in data collection.

Provenance

Many organizations now exhibit a highly visible and ubiquitous 'audit culture' [30, 40], and must demonstrate competence and compliance to a variety of audiences. For example, councils require appropriate data in order to defend, in court, claims of negligence or claims of failing in the council's 'duty of care'. So, for Inspections, complete factual 'audit' information regarding gully-emptying data, including any supplementary photographs, must be electronically signed (authentication enables the stamping of data with the users' identifier) and must be easily and immediately available. When compared to a current paper-based process[1] that Inspections will replace, it is easy to see why the system offers such an attractive and efficient alternative process.

We are cautious to adopt the term 'auditability' as a descriptor of our system design, as this has connotations related to 'people management' issues (e.g. catching and disciplining unwanted behavior). But beyond this, the benefit of these metadata traces is that they enable those that manage the data (whether or not they actively manage personnel) to determine the data's *validity*. We are also aware of the closer association between provenance and trust (e.g. [1, 2, 24]), which indicates that 'provenance' is in greater alignment with our intended design ambitions.

Translucency

The information that is relevant to doing work differs for different users of the system. Web users frequently manage and report on the organization's productivity over a given time period (e.g. annually), and therefore have access to all of the data in the system. Field workers actually need *less* information to work effectively: they need to know which gullies need to be collected or recollected. Inspections enables visibility of relevant peer activities, i.e. only the most recent collections and recollections captured by themselves and their co-workers. This optimizes usability in three ways: 1) it makes for an uncluttered interface on a small screen; 2) it avoids performance reductions that would be caused by pulling down the entire database; and 3) it makes that much

[1] An inspector makes manual notes in a notebook while on an inspection route. When back at the office, s/he fills in appropriate fields on paper forms. Key fields are then transcribed into an electronic system that manages any necessary works orders (tickets), and the paper forms are filed. Following any request for information, e.g. regarding a legal claim, the paper forms are retrieved, electronically scanned and sent to the legal team to form part of a portfolio of evidence.

more accessible what [11] describe as 'socially relevant' information.

Summary: how this all relates to trust

Trust is widely recognized as bringing about a wide range of benefits, including individual, community and organizational well-being, and economic growth [39]. It is cumulative and self-perpetuating in nature [9, 32], and a necessary precondition for successful collaboration. We contend there is an important distinction between accurate data and trusted data. While accuracy is a prerequisite of trusted data, it does not guarantee it; data can be accurate and still not be trusted. So what can design do to foster confidence both in the accuracy of that data and in the workers generating that data, and build trust within the organization?

In empowering crews, Inspections gives them certain responsibilities, and it is therefore important to ensure that they are going to succeed (particularly when failing to record activity can have legal consequences). The 'wizarding' functionality does just that, making sure they remember to fill out all necessary information. Additionally, the system is designed to be forgiving of mistakes — e.g. allowing users to recollect an asset if they have entered it wrong. These features contribute to the generation of 'accurate' data, and go some way toward indicating that workers can be trusted; but more is needed to foster genuine trust.

We suggest that an important element in bridging accurate and trusted data pertains to an understanding of the incentives that motivate workers to collect accurate data. In previous models of gully collection, crew were paid according to the number of gullies they cleaned. In this model, the workers needs (payment) were not aligned with the organizational need to get good quality data and cleaning. To some extent, this problem was addressed by first and second generation GPS tracking solutions, which ensured that cleaning activity could not be forged (i.e. gullies were collected at the point of active cleaning, so workers could not claim to have cleaned additional gullies). At the same time, however, these previous generation solutions did nothing to resolve the rift between worker and organizational needs, so trust in the accuracy of that data was not a designed outcome of these systems; instead the burden was on management to implement top-down organizational (often disciplinary) practices that contributed toward trustworthy data.

Inspections, on the other hand, attends to this problem from the bottom-up by giving users a reason to capture accurate data. As was shown in the discussion of crew and organizational empowerment, there are benefits to all involved for workers to collect accurate data: the system makes everyone's jobs easier, and everyone can be *trusted* to be working toward this mutual incentive. On top of this, the translucency that enables peer visibility contributes further to a sense of collective effort toward a shared goal, which not only breeds trust, but also may contribute to increased job performance (cf. [7]), which in itself would contribute to greater trust in the workers and in the organizational strategy.

Our feedback supports the conclusion that the features that have been designed into Inspections — conscious of its ultimate impact on trust at the early stages of development — combine dynamically to ensure that the data collected is *trusted* as well as accurate.

TRUSTWORTHY BY DESIGN

In 'The Mechanics of Trust: A Framework for Research and Design,' Rieselsberger et al [33] argue that: "If we are to realize the potential of new technologies for enabling new forms of interactions without these undesirable consequences, trust and the conditions that affect it must become a core concern of systems development. The role of systems designers and researchers is thus not one of solely increasing the functionality and usability of the systems that are used to transact or communicate, but to design them in such a way that they support trustworthy action and — based on that — well-placed trust." Our fieldwork and early design thinking identified a series of important and relevant trust considerations for the development of the design.

The examples provided above suggest that many aspects of trust require support to be built very deeply into the application. For example, deciding to ensure that data flows back to mobile users as part of their regular work cycle needs to be addressed at the point at which the overall business process is designed and specified.

More generally, our experience suggests that *trust cannot be easily retrofitted to an application once it is complete*. In this regard we draw a parallel with recent research in the area of privacy support. Like trust, privacy is a fairly abstract concept without clear definitions or boundaries. Engineering support for privacy is known to be extremely challenging at many levels. For example, anonymizing data sets is difficult without complete knowledge of how they might be combined with other data sources while the correct design of user interfaces for describing and managing user privacy needs has proved elusive. The result is that the privacy community have focused on the notion of "Privacy by Design", i.e. the incorporation of privacy principles already at design time, rather than as an afterthought [5].

A good example of privacy by design is the 'Whereabouts clock' [38] that illustrates how privacy can become an active design ingredient. In this work the designers created a wall clock that could only be seen by people in the home — supporting implicit and intuitive 'access control'; was coarse grained (home, work, and school) in line with the information needs of people; and, their wall clock design made the system a shared source of information rather than feeling like a surveillance tool.

We believe that a similar approach, i.e. *trustworthy by design*, is required for building trusted data-gathering systems. While developing a comprehensive toolkit to support trustworthy by design is out of the scope of this paper, we have have drawn on lessons learned from our experiences (above) to suggest eight key principles that should be embedded into the system and its interface at design time:

- *Security:* Trusted data capture must necessarily be underpinned by a secure infrastructure, e.g. it must include measures that ensure tamper resistance.
- *Performance:* Systems — both devices and web portals — must be quick and easy to use in order to encourage users to amend data as necessary.
- *Provenance:* The system must enable users to trace the source of any data capture and amendment activity in a way that aids verification of the validity of that activity.
- *Translucency:* Users must be able to see all relevant data that would help them undertake their work, but no more.
- *Flexibility:* The system must allow users to adjust data when the device is unable to deliver accuracy, e.g. if an obstruction prevents the user from positioning the device over the asset.
- *Value to users:* The system must be designed to deliver value to the user — as opposed to a model that treats users as 'dumb sensors' — to ensure they benefit from producing accurate data.
- *Empowerment:* The system must bring people 'into the loop' and engage their knowledge and intelligence toward a shared goal, such as increasing the quality and ease of work.
- *Competence:* In empowering people and giving them responsibility, the system must build in assurances that users will succeed, e.g. facilitating the submission of all necessary data.

CLOSING REMARKS

We have reported on a data collection system that appears to work toward delivering not only accurate data, but highly trusted data. Much of what we have offered here is post-hoc rationalization of why we have come to believe Inspections works, informed in part by the conversations we have had with users. Having said that, our ambitions at the start had always explicitly pertained to delivering trust, and we are confident that having this goal in mind throughout the development process is a key ingredient in our eventual success. Additional goals, such as providing value to and empowering users, were also explicit in our development process, though we did not understand at the start how integrally it would relate to trust. And finally, while we are confident that design in accordance with our 'trustworthy by design' principles will contribute toward the development of successful systems, successful design further requires open and frequent communication with the users of that system to understand, respond to, and indeed capitalize on emergent organizational affordances. In the future we plan to refine and enrich these 'trustworthy by design' principles, illustrating them in action with further ethnographic accounts and user feedback gathered as the development of Inspections moves from controlled trials to full deployment.

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REFERENCES

1. B. T. Adler, K. Chatterjee, L. de Alfaro, M. Faella, I. Pye, and V. Raman. Assigning trust to wikipedia content. In *Proc. WikiSym'08*, pages 26:1–26:12. ACM, 2008.
2. P. Buneman and W.-C. Tan. Provenance in databases. In *Proc. SIGMOD'07*, pages 1171–1173. ACM, 2007.
3. L. Capra. Engineering human trust in mobile system collaborations. *SIGSOFT Softw. Eng. Notes*, 29(6):107–116, Oct. 2004.
4. J. Cassell and T. Bickmore. External manifestations of trustworthiness in the interface. *Commun. ACM*, 43(12):50–56, Dec. 2000.
5. A. Cavoukian. Privacy by design: The 7 foundational principles. White paper, Information and Privacy Commissioner of Ontario, Canada, 2009.
6. X. Chen, E. Santos-Neto, and M. Ripeanu. Crowdsourcing for on-street smart parking. In *Proc. DIVANet'12*, pages 1–8. ACM, 2012.
7. C.-F. Chiang and T.-S. Hsieh. The impacts of perceived organizational support and psychological empowerment on job performance: The mediating effects of organizational citizenship behavior. *International Journal of Hospitality Management*, 31(1):180 – 190, 2012.
8. M. Cochran. The parental empowerment process: Building on family strengths. In J. Harris, editor, *Child psychology in action: Linking research and practice*, pages 12–33. Croon Helm Publishers, Brookline, MA, 1986.
9. D. Cohen and L. Prusak. *In Good Company: How social capital makes organizations work*. Harvard Business School Press, Boston, MA, 2001.
10. M. Engström, B. Wadensten, and E. Häggström. Caregivers' job satisfaction and empowerment before and after an intervention focused on caregiver empowerment. *Journal of Nursing Management*, 18(1):14–23, 2010.
11. T. Erickson and W. A. Kellogg. Social translucence: an approach to designing systems that support social processes. *ACM Trans. Comput.-Hum. Interact.*, 7(1):59–83, Mar. 2000.
12. J. Froehlich, M. Y. Chen, S. Consolvo, B. Harrison, and J. A. Landay. MyExperience: a system for in situ tracing and capturing of user feedback on mobile phones. In *Proc. MobiSys'07*, pages 57–70. ACM, 2007.
13. D. Gambetta. Can we trust trust. *Trust: Making and breaking cooperative relations*, pages 213–237, 2000.

14. H. Garfinkel. A conception of and experiments with "trust" as a condition of concerted stable actions. *The production of reality: Essays and readings on social interaction*, pages 381–392, 1963.
15. H. Garfinkel. Studies of the routine grounds of everyday activities. *Social problems*, 11(3):225–250, 1964.
16. R. Harper, R. Procter, D. Randall, and M. Rouncefield. 'Safety in numbers': calculation and document re-use in knowledge work. In *GROUP'01*, pages 242–251. ACM, 2001.
17. R. Hartson. Cognitive, physical, sensory, and functional affordances in interaction design. *Behaviour & Information Technology*, 22(5):315–338, 2003.
18. P. Hinds and C. McGrath. Structures that work: social structure, work structure and coordination ease in geographically distributed teams. In *CSCW'06*, pages 343–352. ACM, 2006.
19. A. Jøsang, R. Ismail, and C. Boyd. A survey of trust and reputation systems for online service provision. *Decis. Support Syst.*, 43(2):618–644, Mar. 2007.
20. S. S. Kanhere. Participatory sensing: Crowdsourcing data from mobile smartphones in urban spaces. In *Proc. MDM'11*, pages 3–6, Washington, DC, USA, 2011. IEEE Computer Society.
21. Legislation.gov.uk. Flood and water management act 2010. `http://www.legislation.gov.uk/ukpga/2010/29/contents`.
22. S. M. Liu, K. Unsworth, R. Fidel, and H. J. J. Scholl. Fully mobile wirelessly connected technology applications: Organizational communication, social, and information challenges. *Proc. ASIS&T*, 44(1):1–20, 2007.
23. J. Lord and P. Hutchison. The Process of Empowerment: Implications for Theory and Practice. *Canadian Journal of Community Mental Health*, 12(1):5–22, 1993.
24. C. A. Lynch. When documents deceive: Trust and provenance as new factors for information retrieval in a tangled web. *Journal of the American Society for Information Science and Technology*, 52(1):12–17, 2001.
25. S. Marsh and J. Meech. Trust in design. In *CHI EA '00*, pages 45–46, New York, NY, USA, 2000. ACM.
26. I. Medhi, M. Jain, A. Tewari, M. Bhavsar, M. Matheke-Fischer, and E. Cutrell. Combating rural child malnutrition through inexpensive mobile phones. In *Proc. NordiCHI'12*, pages 635–644. ACM, 2012.
27. D. A. Norman. *The Design of Everyday Things*. Basic Books, Inc., New York, NY, USA, 2002.
28. S. Patnaik, E. Brunskill, and W. Thies. Evaluating the accuracy of data collection on mobile phones: a study of forms, SMS, and voice. In *Proc. ICTD'09*, pages 74–84. IEEE Press, 2009.
29. N. A. Peterson and M. A. Zimmerman. Beyond the individual: Toward a nomological network of organizational empowerment. *American Journal of Community Psychology*, 34(1–2):129–145, September 2004.
30. M. Power. *The Audit Explosion*. Demos, London, 1994.
31. M. Power. The audit society: Rituals of verification. *OUP Catalogue*, 1999.
32. R. Putnam. *Bowling Alone: The Collapse and Revival of American Community*. Simon and Schuster, New York, 2000.
33. J. Riegelsberger, M. A. Sasse, and J. D. McCarthy. The mechanics of trust: a framework for research and design. *International Journal of Human-Computer Studies*, 62(3):381–422, 2005.
34. E. Rocco. Trust breaks down in electronic contexts but can be repaired by some initial face-to-face contact. In *CHI'98*, pages 496–502. ACM Press/Addison-Wesley Publishing Co., 1998.
35. E. Rocco, T. Finholt, E. C. Hofer, and J. Herbsleb. Designing as if trust mattered. *Collaboratory for Research on Electronic Work (CREW) Technical Report*, 2000.
36. Y. Schwartzman and T. S. Parikh. Establishing relationships for designing rural information systems. In *CHI EA'07*, pages 1845–1850. ACM, 2007.
37. S. E. Seibert, G. Wang, and S. H. Courtright. Antecedents and consequences of psychological and team empowerment in organizations: A meta-analytic review. *Journal of Applied Psychology*, 96(5):981–1003, September 2011.
38. A. Sellen, R. Eardley, S. Izadi, and R. Harper. The whereabouts clock: early testing of a situated awareness device. In *CHI EA'06*, pages 1307–1312. ACM, 2006.
39. B. Shneiderman. Designing trust into online experiences. *Commun. ACM*, 43(12):57–59, Dec. 2000.
40. M. Strathern. *Audit Cultures*. Routledge, London, 2000.
41. D. Tjondronegoro and T.-S. Chua. Transforming mobile personal life log into autobiographical multimedia echronicles. In *Proc. MoMM'12*, pages 57–63. ACM, 2012.
42. I. O. Ugboro and K. Obeng. Top management leadership, employee empowerment, job satisfaction, and customer satisfaction in TQM organizations: an empirical study. *Journal of Quality Management*, 5(2):247 – 272, 2000.
43. L. Viljanen. Towards an ontology of trust. In *Proc. TrustBus'05*, pages 175–184, Berlin, Heidelberg, 2005. Springer-Verlag.
44. D. M. Vyas, C. M. Chisalita, and A. J. Dix. Dynamics of affordances and implications for design. Technical Report TR-CTIT-08-36, Centre for Telematics and Information Technology University of Twente, Enschede, May 2008.

45. E. Whitmore. Participation, empowerment and welfare. *Canadian Review of Social Policy*, 22:51–60, 1988.

46. X. Zhang and Q. Zhang. Online trust forming mechanism: approaches and an integrated model. In *Proc. ICEC'05*, pages 201–209. ACM, 2005.

47. M. A. Zimmerman. Empowerment theory: Psychological, organizational, and community levels of analysis. In J. Rappaport and E. Seidman, editors, *Handbook of Community Psychology*, pages 43–63. Plenum, New York, 2000.