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Exploiting Big Data from Mobile Device Sensor-Based Apps: Challenges and Benefits

Sensor data gathered from mobile devices generates big data, which can help organizations continuously monitor a wide range of processes in ways that prompt actions and generate value. However, generating reliable data from such devices is not straightforward and presents a variety of challenges. This article describes the challenges and provides guidelines based on a case study of "Street Bump," a mobile device app that the City of Boston uses to facilitate road infrastructure management.[1,2]

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Sensor Data from Mobile Devices Provides New Opportunities

In the world of big data, organizations are increasingly turning to mobile devices as new sources of data derived from continuously monitoring a wide range of processes and situations. Mobile devices can facilitate the gathering of data from a diverse set of internal and external[3] stakeholders, including employees, customers and citizens willing to "donate" their data. Moreover, this data can be used in myriad ways. For example, sensor data on how an automobile is driven is providing big benefits for organizations ranging from government agencies to insurers.[4,5]

Facilitated by the "Internet of Things (IOT)," donated sensor data generated from users' mobile devices provides important new opportunities. As originally conceived, the IOT includes all kinds of devices connected to the Internet and to each other, generating sensor-based signals independent of human intervention. As noted by Ashton,[6] *"We need to empower computers with*

1 Cynthia Beath, Jeanne Ross and Barbara Wixom are the accepting senior editors for this article.
2 An earlier version of this article was presented at the pre-ICIS SIM/MISQE workshop in Orlando, Florida, in December 2012. In addition to the workshop participants, the author would like to thank anonymous referees and special issue editors, as well as Chris Osgood and James Solomon from the City of Boston.
3 Piccoli, G. and Pigni, F. "Harvesting External Data: The Potential of Digital Data Streams," *MIS Quarterly Executive* (12:1), 2013, pp. 53-64.
4 Vaia, G., Carmel, E., DeLone, W., Trautsch, H. and Menichetti, F. "Vehicle Telematics at an Italian Insurer: New Auto Insurance Products and a New Industry Ecosystem," *MIS Quarterly Executive* (11:3), 2012, pp. 113-125.
5 Mann, T. "Data Driven: New Program to Fix New York City Streets," *The Wall Street Journal,* August 30, 2013.
6 For a summary of the history of the Internet of Things, see Ashton, K. "That 'Internet of Things' Thing," *RFID Journal,* June 22, 2009 (http://www.rfidjournal.com/articles/view?4986).

their own means of gathering information, so they can see, hear and smell the world for themselves, in all its random glory ... sensor technology [that] enable[s] computers to observe, identify and understand the world—without the limitations of human-entered data.” With this concept of the IOT, humans play a relatively passive role, simply ensuring that their mobile devices are switched on and generating data. As further noted by Ashton:[7] *“people have limited time, attention and accuracy—all of which means they are not very good at capturing data about things in the real world.”* In addition, with activities such as driving, it is dangerous or illegal for people to simultaneously perform the activity and provide associated data. Mobile devices can be configured to capture that data and relieve humans of the responsibility.

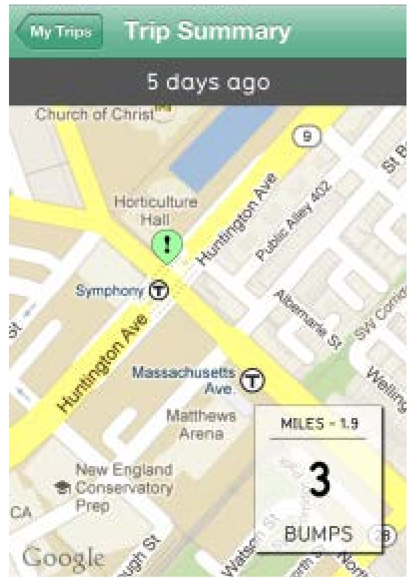
Although sensor data from mobile devices can help generate deep insights and create value, gathering this kind of data does have its challenges. Using sensor data is not simply a matter of connecting devices together. Instead, companies need to identify and address the technical, behavioral, organizational and privacy issues arising from mobile device sensor initiatives.

Based on a case study of the City of Boston’s “Street Bump” app available for iPhones, this article describes the emerging challenges and proposes approaches to overcoming them. With Street Bump, users place their iPhone in their cars, turn the app on and drive. The app captures data about the location of potential potholes that are encountered, which can then be uploaded to a central server. City of Boston managers actively mitigate the challenges arising from the app so that the data can be used to provide benefits both to the city and to app users.

The Street Bump App

The City of Boston has over 800 miles of roads and repairs over 19,000 potholes every year.[8] Historically, potholes have been identified by city workers. As noted by Mathew Mayrl from the City of Boston, *“We probably have 30 to 40 staff out there each day, and one of their responsibilities is to identify potholes.”*[9] In 2012, the City of Boston developed an app called “Street Bump” (see Figure 1) to allow virtually anyone to capture and report pothole data using their iPhone.

Figure 1: The Street Bump iPhone App



Source: http://www.newurbanmechanics.org/projects/streetscapes/bump/

In theory, drivers simply need to download and activate the app, put their phone on the dashboard or in a cup holder and drive. Using this approach, an army of mobile phone users driving the streets of Boston can replicate the work of city employees traveling block to block, surveying streets and looking for potholes. When a driver runs over a pothole, the phone captures the location of the pothole and then sends that location to a cloud-based computer, which records the reported pothole information with the location of other potholes so that they can be scheduled for repair in a timely manner. Specifically, as noted by Nigel Jacob from the City of Boston, *“[Street Bump] provides a new way for people to donate their data in solving public good problems.”*[10]

Street Bump is being recognized as an important emerging innovation. For example, City of Boston Co-Chairs of the Mayor’s Office of New Urban Mechanics (Nigel Jacob and Chris Osgood),

7 Ibid.

8 Ngowi, R. “App detects potholes, alerts Boston city officials,” *USA Today,* July 20, 2012 (http://usatoday30.usatoday.com/tech/news/story/2012-07-20/pothole-app/56367586/1).

9 *Bump App Detects Potholes, Alerts City Officials,* Associated Press, July 20, 2012 (http://www.youtube.com/watch?v=yxAYLA405pU).

10 Ngowi, R., op. cit., 2012.

whose responsibilities include the Street Bump app, were awarded the 2013 Tribeca Disruptive Innovation Award.[11]

Street Bump Technology

The Street Bump app[12] uses the mobile phone's accelerometer to detect potential potholes, and the phone's global positioning system (GPS) capabilities to gather location information of that pothole. As users of the app drive around Boston, a constant stream of data is captured by the iPhones and analyzed for "bumps." Street Bump currently provides users with feedback in the form of a summary of the number of bumps and the length of the trip (see Figure 1). The user then decides whether to submit the bump data to the City Works Department, which is responsible for repairing potholes. If so, the data is uploaded to a server, and likely road problems are submitted to the city via open311,[13] where they are classified as potholes that need to be fixed or as known obstacles such as speed bumps.

GPS software maps the location of potential potholes with an accuracy of within 18 feet. If an adjacent bump is encountered, the two become a cluster, and the center is calculated as the midpoint between the two.

The cloud servers to which the app sends data are hosted by Connected Bits, Boston's partner on the project, with the data stored in a MongoDB database. City users can generate queries to analyze the data collected in that database.

Filtering Out Bumps that are not Potholes

Although Street Bump was designed for use by citizens, the initial implementation has been restricted to data gathered by city employees. In late summer and fall of 2012, 25 employees used the app to gather data on bumps in the highway. By the end of the year, the city realized that Street Bump was only about 10% effective in determining the existence of a genuine pothole, rather than a speed bump or a raised or damaged casting. Street Bump did not discriminate well between those different types of road anomalies. To improve the effectiveness, the city captured the location of known objects, which were bumps but not potholes. The app also uses different algorithms to filter out alternative sources of movement and bumps, such as joints in bridges, speed bumps, utility damage to streets and damaged street hardware (e.g., manhole covers).

These changes improved the pothole detection accuracy rate to between 30% and 40%. But even with this higher level of accuracy, managers still needed to have a person physically identify the existence of a pothole before it could be confirmed as one that needed to be repaired. Unfortunately, physical confirmation of the existence of potholes is a costly process; therefore, the city continuously works to improve the accuracy rate over time.

City officials also made the app widely available to the public to facilitate testing by individuals, which has resulted in useful feedback. For example, users discovered that the location of the phone in the car and the type of car could result in different data being generated for the same road anomaly.

Potential Benefits of Generating Data from Mobile Devices

Mobile device apps like Street Bump offer the opportunity to provide continuous monitoring and thus generate big data. For example, mobile phones constantly monitor location and other variables, such as heart beats, noise levels and movement. These capabilities can generate significant quantities of data and ultimately provide direct, indirect and emerging future benefits.

Direct Planned Benefits

Mobile apps can continuously monitor situations and conditions from many different sources or locations and from a wide range of users. The cost of gathering this data generated in real time is potentially low. In addition, it can be analyzed and integrated with business processes to solve problems.

The cost of finding and fixing potholes in the United States is substantial. For example, in the winter and spring time, New York City has 40 crews working 24 hours a day, seven days a

11 http://www.tribecadisruptiveinnovationawards.com/?p=209.

12 The app can be downloaded at https://itunes.apple.com/us/app/street-bump/id528964742?mt=8.

13 Open311 is a collaborative model and open standard for civic issue tracking.

week, simply finding and filling potholes.[14] In the case of Street Bump, rather than having crews find the potholes, that task can be carried out by mobile phone owners, thus reducing personnel, equipment and other costs for the city.

There are many individual stories of how potholes have “destroyed” everything from school buses to Ferraris. Reportedly, deaths have even resulted from potholes.[15] Street Bump allows both major anomalies in the road infrastructure and “emerging” potholes to be identified so that they can be fixed before they become a major traffic hazard, thus reducing the costs of potholes to the public. Speed of identification is particularly important because the cost of fixing potholes can increase exponentially as the quality of the road deteriorates.

Indirect Benefits

As data is gathered using mobile apps, managers gain real-time insights into the processes being monitored. Continuous monitoring generates data about the process, facilitating transparency and eliminating information asymmetries.[16] As data is gathered using mobile apps, managers can align their actions, strategies, processes and organization with the information and knowledge generated from the processes being monitored.

Organizations can use the insights into the information asymmetries to generate competitive or political advantages over competitors so they win the support of customers, voters, etc.

New data also provides the opportunity to change processes and organizational relationships. When it implemented Street Bump, the City of Boston found that it had over 300,000 castings on the city streets and sidewalks. Although some belong to the city, the majority belong to other organizations such as the water company. This has led to monthly meetings to keep both sides informed and allows tracking and management of the condition of those castings.

Potential Future Benefits

In the case of Street Bump, the plan is to integrate pothole identification capabilities into other systems that can facilitate the pothole repair process. For example, Street Bump could be integrated with a system that allows rapid response and resource allocation in the form of a pothole management system. Such a system could provide an improved capability to facilitate management of city resources and help guide resource allocation decisions and infrastructure investment.

Street Bump has additional potential future benefits. For example, the existence of potholes may indicate other highway management problems, such as bridge joint disrepair or manhole cover disrepair or of the need for more extensive road repairs. Pothole data may also support the analysis of other city services. For example, to what extent are potholes predictive of problems leading to police and fire calls? To what extent do potholes limit the speed of response of the police and fire services? Linking real-time quality pothole databases to other databases enables these and other related problems to be investigated.

Challenges of Sensor-Based Mobile Device Apps

Although sensor-based mobile device apps can provide significant benefits, there are also challenges. We illustrate some of the challenges by describing the experiences with Street Bump.

Information Systems Management Issues

Sensor-based mobile device apps present challenges that require management decisions. Managers need to consider what types of devices an app will be available for and the scalability of the supporting infrastructure. They also need to ensure that the data collected is of sufficient quality to meet business requirements.

Device Standardization. Sensor signals can vary according to the particular type of mobile device, and various device characteristics, such as the hardware and operating system, can impact the signal. For example, the accelerometers used in different mobile phones vary. Thus, given the same input, the movement and shocks captured by different types of mobile phones can be different. Accordingly, to generate a

14 “City Grapples with Thousands of Potholes,” *NY1 News*, February 9, 2011 (http://www.ny1.com/content/top_stories/133598/city-grapples-with-thousands-of-potholes).

15 Reeves, J. “Death by pothole,” *The Post and Courier,* December 22, 2010 (http://www.postandcourier.com/article/20101222/PC1602/312229952).

16 Information asymmetries occur when two people have different information about the same thing. If one has additional inside information, he or she can leverage or take advantage of that information.

consistent sensor signal, it may be necessary to standardize on a single type of device, at least initially. Alternatively, additional measures must be put in place to make the signals and their interpretations similar.

In the case of Street Bump, the iPhone accelerometer, the Android accelerometer and other phone accelerometers and their operating systems generated different signals from the same bump in the road. Further, different Android phones had different accelerometers. As a result, in order to ensure signal reliability and data consistency, the City of Boston decided that, initially, data would only be gathered from iPhones.

Infrastructure Scalability. Scalability of the supporting IT infrastructure can be a key concern when collecting data from mobile devices. As use of an app moves from a few users to many users, facilities can be overwhelmed by increasing data volumes.

In the case of Street Bump, the City of Boston mitigated some of the scalability issues by initially capturing Street Bump pothole information only from City employees. This prototyping approach was taken so that officials could begin to understand some of the key data management concerns associated with data volumes before having to process and store the data from a larger number of users.

Data Quality. The quality of technology in mobile devices can limit the quality of the information gathered from the devices, compromising the precision and limiting the use of the data for its intended purposes. The sensitivity of components such as accelerometers or GPS capabilities differs according to the device.

With Street Bump, location information from iPhones is accurate to within 18 feet; therefore, multiple sources of the same anomaly can be used to triangulate to get a better fix on the actual location. For example, when multiple users find an anomaly at the same or a similar location, the redundancy in the data generated provides better evidence for the existence and location of a potential pothole or cluster of potholes.[17]

17 "Boston releases Street Bump app that automatically detects potholes while driving," *MailOnline,* July 20, 2012 (http://www.dailymail.co.uk/news/article-2176783/City-releases-motion-detecting-Street-Bump-app-automatically-detects-reports-potholes-driving.html).

Data Donation Management Issues

Controls need to be considered when mobile devices are used to collect data donations from the public. Organizations must also plan how they will respond to the donations. Accordingly, managers must consider the context of the device use, user behavior and user incentives and expectations.

Context of Device Use. Although gathering sensor data from mobile devices may seem relatively mechanistic, such data can be influenced by the use of the device, including the context in which it is used. For example, Street Bump users found that the location of the mobile phone in the car, the type of car and which phone is used make a difference to whether or not a pothole is identified. One user noted that he drove the same route with two different cars. The first car, a four wheel drive vehicle, found 50 different potholes, whereas the second, a Jaguar, found only one over the same 3.5 mile journey. That same user noted that the location of the phone in the car also made a difference on whether potholes would be detected.

User Behavior. User behavior can also influence what the device finds. For example, in the case of Street Bump, a driver might consciously slow down or drive around potholes to better preserve his or her car, which clearly limits the potential success of the app in finding potholes. Alternatively, although unlikely, drivers, intent on providing the city with detailed pothole information could speed-up as they drive through potholes. Each behavior would result in different findings from the exact same environment.

User Incentives and Expectations Management. A key challenge in using a mobile app to facilitate data collection is to ensure the app is used. If the app is too costly or there are no incentives for using it, there are not likely to be many data donations. In the case of Street Bump, the app was available as a free download, minimizing the direct costs to iPhone users. Further, users likely anticipated that by driving with the app on in their car, potholes would be identified and the city would use that information to fix the potholes. There would be a direct user benefit because potholes on the roads they used would more likely be identified and fixed. In addition, users may have "felt good" about being part of a network that provided signals to monitor road quality. All in all, there would be definite incentives to using Street Bump.

When users donate data, they likely have expectations for how that data will be used. To accommodate those expectations, organizations need to provide feedback in different situations. However, once the signal is received by the organization, what kind of feedback should occur, and what events should drive the feedback to the information provider? To complicate the issue, since mobile devices work passively while users are performing other activities, it may be that users do not notice that the devices are generating usable data. As currently configured, Street Bump does not capture information about users, which means there is no mechanism for providing feedback on whether a pothole was fixed, thus limiting the ability to link expectations and incentives.

The sensor data generated by Street Bump can influence expectations. If Street Bump finds a bump, citizen expectations are that the city should be able to fix it. However, Street Bump identifies many more casting bumps than actual potholes, but most of those castings are not owned or maintained by the city.[18] As a result, the city cannot fix many of the bumps identified by Street Bump.

Application Management Issues

Application management is concerned with delivering the expertise, skills and solutions necessary to successfully build, run and evolve applications. Applications provide the interface between the IT infrastructure and the user. Designing user-friendly interfaces requires the appropriate domain expertise. In addition, organizations need to understand the issues associated with the inherent biases of using mobile devices.

Domain Expertise. Organizations may or may not have the necessary expertise to develop the specific app. Those without the appropriate expertise must consider alternative options such as outsourcing. The City of Boston outsourced the development of Street Bump, removing the need to acquire internal expertise about the app. The outsourcer was chosen as a result of a "challenge" (or competition) that invited interested parties to propose solutions.[19]

Inherent Biases. Using mobile devices for data collection can result in various inherent biases. To participate, a user must have access to the device and app, and the context. If users do not have access to any of those three, they will not be involved in generating data, and resource allocation decisions may be made to their detriment. As a result, using sensor-generated data can result in a bias—a kind of "digital divide"[20] between participants who can afford the app, device and context, and non-participants who cannot afford them.

To capture road infrastructure information with Street Bump, the user needs to have the app, an iPhone and a car. Although the app is free, not everyone has access to an iPhone and car. This may result in disproportionate amounts of data being generated about some roads, which can result in greater attention being given to road infrastructure in some locations. To date, the City of Boston has circumvented this issue because only city personnel are used for data capture.

Privacy Management Issues

Mobile apps provide the ability to capture substantial broad-based sensor information generated by individuals based on their behavior. Although users can limit which information they will share by turning the app on or off, potentially confidential information could be shared inadvertently, or life-style information could be embedded in the donated data. As a result, data donation or data sharing can result in both the perception of and actual invasion of privacy. Privacy concerns may also cause the user to be selective about when the app is switched on. In addition, organizations may have to forego the advantages of personalization and contextualization because of privacy concerns.

Perceived Privacy Invasion. The perception of an invasion of privacy is illustrated by accounts of how cities' use of other technologies has compromised privacy. For example, there have been reports on how traffic cameras have captured cheating spouses running red lights; when the pictures were sent to their home as evidence, their spouse saw them with someone

18 Moskowitz, E. "App shows jarring role of cast-metal covers in Boston," *The Boston Globe*, December 16, 2012 (http://www.bostonglobe.com/metro/2012/12/16/pothole/2iNCJ05M15vmr4aGHACNgP/story.html).

19 Osgood, C. "Challenge: Build an App to Detect Potholes," (http://www.newurbanmechanics.org/2011/02/09/challenge-build-an-app-to-detect-potholes/).

20 Norris, P. *Digital Divide,* Cambridge University Press, 2001.

else. Thus, an important question to address is to what extent users will perceive sensor-based mobile apps that can track their every move as an invasion of their privacy?

Actual Invasion of Privacy. There can be privacy issues associated with knowledge about the user's life style that can be discovered from the donated data.[21] Since sensor data from mobile devices is gathered unobtrusively, and potentially continuously, data could be gathered that would be intrusive to the data provider's life. For example, the sequence of potholes provided by Street Bump could result in information about a route to a hospital or doctor. If that information were made available to others, it might be used against the data provider in situations such as insurance policies.

The City of Boston aimed to build a "strong relationship of trust" as part of its citizen-centric approach. As a result, when capturing bump location, any user information is stripped from the data. By stripping out user information, it is impossible to generate "user profiles" to analyze or investigate particular user behavior, thus assuring data-provider privacy.

Addressing privacy concerns can result in substantial costs. If data is cleansed of many of its identifying features, the ability of the organization to generate knowledge from data can be limited. In the case of Street Bump, eliminating user and pothole sequence information can severely limit additional knowledge that might be mined from the data.

Selective Use to Preserve Privacy. As a result of privacy concerns, users are likely to be selective about the information that they disclose to the system. In particular, privacy issues may influence the time when a user turns on a sensor-based app and how long it is turned on for. In the case of Street Bump, users may be selective about the routes for which they allow the system to capture data. For example, the user might turn the app on for day-to-day activities, such as driving to work, but not turn it on for after-work activities or trips for medical purposes. This behavior can lead to potential biases in the information that is generated.

Personalization and Contextualization Privacy Issues. Different users have different preferences. As a result, information is often gathered from users to personalize their usage. Unfortunately, the more personalization built into the mobile device and app, the greater the potential loss of privacy. For this reason, the City of Boston has chosen to exclude all personal information from Street Bump's use to provide maximum privacy.

Similarly, organizations can choose the extent to which device capabilities are "optimized" for the specific context. In particular, organizations determine the extent to which they will account for context variables that influence mobile device sensor signals. In the case of Street Bump, the potential context information includes the type of device (iPhone), relevant technology within the device (GPS, accelerometer), the location of the device (e.g., car type and location of device within the car) and other factors.

The more fully the context information is considered and used, the "better" the potential performance of the app at capturing sensor data to accomplish the task at hand. Unfortunately, in some cases, providing context information can result in loss of privacy. For example, if the user employs a unique context or the context includes user characteristics, then the context can point directly to a particular user. Thus, in the case of Street Bump, there currently are no plans to gather context information from citizens since the city wants to preserve privacy.

Recent and Future Street Bump Developments

Street Bump is still evolving. Recent developments over the last year, some of which have been mentioned above, include:

- At the time of writing, the donated data is generated only by city employees. However, the City of Boston expects that as the accuracy of pothole detection increases, it will begin using data donated by citizens.
- To date, the city has not actively tried to engage citizens in data collection since it is still piloting Street Bump. As a result, less than 5,000 users worldwide have downloaded the app. Although data from users in other cities and countries is captured, it is neither mapped nor used.

21 O'Leary, D. "Knowledge discovery as a threat to database security," *Knowledge Discovery in Databases,* AAAI Press/MIT Press, 1991, pp. 507-516.

- Because of recent national and international concerns with privacy,[22] Boston has discussed the potential development of a "nutritional label" that would indicate the key privacy protection built into the app.
- The city is considering developing an app that is similar to Street Bump but is only used by city employees. The revised version would allow capture of specific trip information, thus allowing more detailed data capture than would be possible with data donated from the public.
- The city expects that, in the future, Street Bump will become an open source app, thus facilitating collaboration with other cities and developers.

Guidelines for Avoiding the Pitfalls of Sensor Data Generation

Based on the City of Boston's experience with Street Bump, the following seven guidelines will help organizations avoid the pitfalls of sensor data generation.

1. Make Data Actionable

For management to depend on and use the data generated from mobile device sensors, it must be timely and reliable—i.e., it must be actionable. In general, such data is timely but may not be reliable. In the early stages of a project, it is important to assess the reliability of the data being captured, and then work over time to improve reliability to achieve an acceptable level for the data's ultimate intended use.

2. Prepare for Likely Organization and Process Changes

The rate at which mobile devices and apps collect sensor data may outstrip the organization's ability to react to the insights generated from that data. For example, StreetBump can find potential potholes faster than the city can fix them. To reconcile this disconnect, managers may need to reengineer processes within the organization—for example, by leveraging automation or alerts—so that the organization can process and act on sensor data appropriately.

3. Design Personalization and Contextualization to Match Privacy Requirements

Organizations should determine the extent to which users can personalize apps and design them accordingly. Whereas personalization enables users to better meet their needs, the greater the level of personalization, the greater the potential loss of privacy. These conflicting influences must be balanced by managers who understand the unique risks of the initiative.

4. Plan for Growth

Organizations should anticipate the potential growth of sensor data and leverage advanced technologies, such as cloud computing and MapReduce,[23] to facilitate scalability. Sensor data can be divided into multiple pieces—either at the device level or event level—so that the data can be processed in parallel, which further facilitates scalable solutions.

5. Set a Narrow Band of Device Standards and Expand over Time

Organizations should initially choose to standardize on a particular device to facilitate sensor signal standardization from mobile devices. Over time, the device options can be extended to include related devices (e.g., iPads in the case of the iPhone) or emerging new devices that gain in popularity (e.g., in a recent poll, *USA Today* readers felt that Android users would outnumber iPhone users in three years.[24])

6. Pilot Test with Employees

When possible, organizations should pilot test mobile device sensor apps internally to more fully understand their use and effects—and to mitigate risks associated with unexpected issues from engaging with customers or external stakeholders. Pilot testing will show how user behavior with the mobile devices can influence

22 Satran, R. "NSA Data Fight Could Signal Privacy War," *US News and World Report,* July 30, 2013 (http://money.usnews.com/money/personal-finance/mutual-funds/articles/2013/07/30/nsa-data-fight-could-signal-privacy-war).

23 Dean, J. and Ghemawat, S. "MapReduce: Simplified Data Processing on Large Clusters," *Communications of the ACM* (51:1), January 2008, pp. 107-113.

24 *USA Today*, June 26, 2013, p. 1.

results. For example, in the case of Street Bump, snow and ice will likely cause drivers to slow down and be more cautious, which will affect the sensor data recorded for potholes.

7. Offer Incentives and Feedback while Managing Expectations

A mobile sensor app ultimately needs to make a difference in the life of the data provider, so organizations need to ensure that users can identify the value proposition associated with donating data from their mobile apps. Organizations should continually gather information about user costs and benefits, possibly by running experiments or by conducting periodic surveys.

Concluding Comments

The huge amount of data generated from the sensors in mobile devices can offer unique opportunities to provide continuous monitoring of a range of processes, in real time, potentially mitigating information asymmetries. But capturing and making use of the sensor data is not as simple as just adding a new data source. This article has described the challenges organizations face with sensor-based mobile device apps and provided guidelines for avoiding the pitfalls.

Appendix: Research Methodology

This study is based on data collected between June 2012 and July 2013. Information was gathered from multiple sources, including:

- *Social media:* Street Bump and Connected Bits have Twitter accounts that provide insights.
- *News media:* Several videos (for example, by the Associated Press) about Street Bump are available on YouTube. These videos include interviews with City of Boston personnel. In addition, news media, ranging from *USA Today* to *The Boston Globe,* have published articles about Street Bump.
- *Google Group:* There is a Google Group devoted to Street Bump. As part of the research, the author monitored contributions to that group.
- *Phone interviews with City of Boston personnel:* The author interviewed James Solomon (Street Bump Manager, Mayor's Office of New Urban Mechanics) and Chris Osgood (Co-Chair, Mayor's Office of New Urban Mechanics), both from the Public Works Department. Without their help, this article would not have been possible.

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