Offering Sensor Network Services Using the Postal Delivery Vehicle Fleet

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1. INTRODUCTION

Postal operators, for example, USPS, or their business partners could offer a novel category of data collection services arising from the ubiquity and route structure of the postal delivery fleet. This paper, for the first time, proposes that mobile sensors mounted on postal trucks could collect and aggregate a variety of important data as a byproduct of postal delivery, taking advantage of efficiencies of scope and scale. The data collected might include, among others, air pollution levels, weather data, sensing of chemical and biological agents, and areas of weak cell phone service. If the market challenges could be addressed, these services could provide substantial public good.

Section 2 provides a description of the technologies involved and the basic rationale for integrating sensor network services with postal operations. Section 3 describes potential applications. Section 4 discusses market aspects and mechanisms for developing functioning markets. Section 5 provides conclusions.

2. TECHNICAL DESCRIPTION AND RATIONALE

Sensors mounted on postal trucks could collect and upload important local data as a by-product of postal delivery. USPS or its business partners could lease out space on selected postal trucks to permit installation of smart sensors with radio links to collect and transmit various types of data, and record the location and time of each piece of data. Postal routes are tailor-made for a sensor network because postal delivery routes reflect locations of human activity and the trucks traverse those routes daily. The existing set of routes closely resembles the structure of an efficient ground-based mobile sensor network designed from scratch.

The concept would not add appreciable labor hours, route diversions or changes in procedure. It would not add tasks to the drivers' workload that would detract from mail delivery, although drivers may be able to provide feedback about proper functioning of the sensor system. While sensors at fixed locations are confined by functional and geographic limitations, a mobile sensor network using postal trucks can provide tightly-interlaced, overlapping fine-grained coverage across a broad area. It constitutes a virtual "cloud" of sensors spread throughout a region. Individual sensor points move around, but the aggregate "cloud" remains deployed and well-dispersed much of the day, most days of the week. A network of mobile sensors can reach nearly everywhere in the country, yet can also achieve a high degree of geographic specificity and selectivity. It permits targeting of routes near a specific subset of industrial facilities, specific types of neighborhoods or lists of critical infrastructure points, depending on customer needs. Factories producing or using a particular chemical may require monitoring nationally, and to do this a small subset of neighboring postal routes can be selected.

Measurements can be done nationally, regionally, locally and selectively down to an individual route. The system allows collection of finely- or coarsely-spaced data. The sensing area can cover a wide swath of the nation or just a single metropolitan area, or a location conforming to a set of specific target criteria, even locations cutting across sections of specific postal routes.

The rate of deployment is also flexible -- sensor packages can be deployed simultaneously across a set of trucks for rapid data collection, or else in stages. Thus, the number of sensor packages is adaptable – the number of trucks required for a particular task can be reduced by gathering data on a progressive basis. Once a route is run the requisite number of times and adequate data is obtained, the sensor packages can be moved to another set of routes. This provides for great utility in sensor deployment and extraction of maximum value from their use.

Flexibility of the concept is enhanced by availability of several data acquisition options. Mechanisms may include accumulating or averaging data over time to establish a baseline or to locate irregular phenomena, adapting the deployment and use of sensors based on the data received, and accommodating multiple sensors on the same vehicle platform. Data can be recorded and provided continuously, intermittently or on predetermined trigger points, or once daily. Data also can be used to trigger alerts/alarms.

Using postal vehicles as the basis for a sensor network taps the principles of a concept that has been called telecartography or geoinformatics, terms meaning the tying together of measurement data with its origin location. While the technical literature suggests that sensor data gathered in a random, unplanned manner and labeled with location and time coordinates can produce some useful mapping over time, postal-based fixed route data collection would produce more useful data more quickly and with greater efficiency. Furthermore, on fixed routes, data from the same locations are collected daily for a large number of locations, reducing potential sources of error and increasing opportunities for productive data analysis.

Hardware for such a system would consist of a detector to measure some signal or parameter, along with a transducer to convert the results into an electrical signal that can be digitized. The system would require a means of getting the measurable quantity to the detector, for example an air funnel for atmospheric sensing, or a suitable radio antenna for radiofrequency detection. In addition, a system to transmit the data, a source of power (either batteries or access to vehicle power), a mounting interface, and packaging would be needed. Electrical power requirements are modest and would not interfere with vehicle operation. The equipment would be required to operate over a wide range of operating conditions, and should be designed so as not to require any attention from the letter carrier / driver. Location- and time-stamping of the data stream would be accomplished with a Global Positioning System (GPS) device; such devices are now inexpensive and highly portable. Data transmission can be performed with a wireless device analogous to a "smart" phone.

Commercial sensors exist for the applications highlighted in this paper.[1] Off-the shelf multispecies gas analyzers exist that can detect a wide range of atmospheric constituents and substances at tiny concentrations.[2] Chemical and biological sensors are increasingly commercially available to detect a wide variety of compounds.[3]

Access to GPS data makes it possible to select a variety of criteria by which data is collected, and how it is uploaded. For some applications, such as for homeland security or detecting chemical releases, the primary value of the system will be in providing an alert mechanism. For others, such as weather data, continuous data collection may be best. Still other applications may benefit most from an evenly spaced geographic distribution of data points. For still others, measurements or data transmission is desired only if some specified contingency occurs. Table 1 identifies several ways in which data can be collected and transmitted.

Table 1: Data Collection and Transmission Modes

Continuous/Real-Time Data Exchange
Continuous Data Exchange with Lagging Buffer
Periodic Measurement (Time Sampling)
Periodic or Opportunistic Transmission (Burst)
Geographic Sampling (Location Sampling)
Sampling with Geographic Constraints
Sampling with Time Constraints
End of Day or End of Route Upload
Alert or Alarm
Contingency Measurement (triggered by an external event or another measurement)
Contingency Transmission (triggered by an external event or a measurement)

Manually/Remotely Triggered Measurements

3. POTENTIAL USES

A variety of potential applications exist. Table 2 lists several potential uses for this type of mobile sensor data, described below, and which form a starting point in identifying customer/market demand.

Table 2: Matrix of Potential Applications for Postal Truck-Borne Mobile Sensors

Application Description	Type of Use	Similar Data Available	Likely Customer Base	Revenue Potential	Technical Feasibility	Conflicts With Postal Mission	Possible Privacy Implications
Chemical Agents	Multiple	No	DHS, States	High	Yes	No	No
Biological Agents	Multiple	No	DHS, States	High	Yes	No	No
Radiological Materials	Multiple	No	DOE, DHS, States	High	Yes	No	No
Air Quality	Continuous	No	EPA, States, Cities	High	Yes	No	No
Environmental Sensing	Continuous	No	EPA, States, USDA, Cities	High	Yes	No	No
Radio/Television Signal Strength	Periodic	Maybe	FCC, Telecoms	High	Yes	No	No
Wireless Signal Strength	Periodic	Maybe	FCC, Telecoms	High	Yes	No	No
Weather/ Meteorological	Continuous	No	National Weather Service	High	Yes	No	No
Pothole Mapping/ Road Assessment	Occasional	Yes	Public Works Departments	Medium	Yes	No	No
Natural Gas Leaks	Multiple	No	Gas Utilities	High	Yes	No	No
License Plate Scanning	Multiple	Yes	Law Enforcement	Medium	Yes	Probably	Yes
Methamphetamine Labs	Multiple	No	Law Enforcement	Medium	Yes	Probably	Yes
Marijuana Farms/ Drug Depots	Multiple	No	Law Enforcement	Low	Yes	Probably	Yes
Illicit Explosives Production	Multiple	No	Law Enforcement	Medium	Yes	Probably	Yes
Photo Imaging	Multiple	No	Google, Law Enforcement, Local Governments	High	Yes	Possibly	Yes
Noise Profiling/ Acoustic Signature	Occasional	No	Zoning, Cities, Research	Low	Yes	No	Possibly
Pest Control	Multiple	No	State, County Governments	Low	Possibly	Possibly	No
Biological Surveys	Multiple	No	Scientific Community	Low	Yes	No	No
Nuclear Radiation Leaks	Multiple	Yes	NRC, Utilities	Low	Yes	No	No
Electric Field Mapping	Occasional	No	EPA, Cities, Scientific Community	Low	Yes	No	No
Magnetic Field Mapping	Occasional	No	EPA, Cities, Scientific Community	Low	Yes	No	No

Other Scientific Investigation	Occasional	No	DoD, DOE, Scientific Community, Universities	Medium	Yes	No	No
Meter Reading	Periodic	Yes	Gas/Water/Elec. Utilities	Low	Possibly	No	No

Homeland Security and Civil Defense: Threats from chemical or biological agents or radiological materials make homeland security (civil defense) a promising application for postal sensors.[4] Rapid detection is critical to public safety in any scenario involving such threats, and sensing a threat earlier provides easier, cheaper and safer options for countering that threat.

Sensor technology is advancing rapidly, enabling the mobile detection of such chemical and biological agents, radiation and radiological material. Ariessohn (2007) describes the potential use of vehicles (starting with the postal fleet) to provide wide-area coverage and continuous monitoring for chemical and biological agents. The U.S. Department of Homeland Security recently announced it is working with cell phone manufacturers to develop phones that can detect poisonous chemicals, carbon monoxide or fires.[5] Similarly, researchers at Purdue University have proposed fitting mobile phones with small radiation monitors to detect dirty bomb radiation.[6] Radiological sensors could detect nuclear leaks from nuclear power plants and other facilities that use nuclear materials.

One of the useful aspects to a postal-based sensing system is the ability to map normal background levels and the location of existing radiation sources. Naturally-occurring and man-made radiation sources can create challenges for nuclear sensing, making it necessary to develop a background model to avoid false alarms and to increase measurement sensitivity. Background mapping using postal sensing would increase the potential value of other dedicated radiological sensing systems.

Air Pollution and Environmental Sensing: Monitoring air quality and conducting environmental assessments is a worthwhile mobile sensor application.[7] Benefit would be derived from the use of sensors to detect and measure the concentration of a broad range of atmospheric compounds and contaminants.[8,9] A precise map of air quality for a particular pollutant would provide feedback on the effectiveness of remediation or prevention measures. In addition, this mechanism could be used as an alert system to detect pollutants exceeding a normal range, emission spikes, toxic releases, leaks or spills. It could also be used to detect excessive concentrations of pesticides or other hazardous or controlled materials near locations where they are applied or used.

Geographically targeted monitoring is possible. The U.S. Environmental Protection Agency, as well as the public safety (emergency response) or environmental offices in the various states, require registration of a wide range of hazardous substances. In the U.S., the national Toxic

Release Inventory (TRI) describes actual or estimated chemicals released in stack emissions or in other ways. Reporting by other offices covers chemicals used or stored on the premises to protect and aid emergency response teams. Those offices publish listings of the facilities that use, emit or store particular pollutants or toxic substances. It is therefore possible to identify postal routes near facilities using or emitting particular chemicals. Those specified routes can be sampled on a limited basis or can be periodically or regularly monitored by postal truck-borne sensors. Available sensors can detect specified chemicals in the air at the desired low range of concentrations with the necessary selectivity.

Broadcasting and Wireless Signal Quality: Weak cellular and wireless signals are a persistent problem for telecom service providers and their customers. This concept can be used to map areas of weak or no signal for cell phone and wireless service, radio and television broadcasting. Mobile sensors can also detect harmful electromagnetic interference in the form of illicit, improper or malfunctioning sources of radiofrequency emissions in the wavelengths reserved for cellular, wireless or broadcasting services.

Wireless telephone and Internet service providers deploy numerous and expensive cellular transmission/reception towers. The towers and associated equipment experience local failures or service degradation. Local geography and terrain can also result in areas of weak or no signal that can cause service difficulties or customer dissatisfaction. Dead spots and weak service zones can migrate over time and may change with weather and seasonal conditions. Existing methods of measuring localized signal quality are costly, and produce maps with insufficient detail. There may also be an undesirable lag time between the partial or total failure of a telecom component and the detection of any resulting service degradation.

The conversion from analog to digital television broadcasting has resulted in certain reception problems. Digital signals propagate differently than analog signals and can be more prone to difficulties from “multipath” effects caused by reflections from buildings and other obstacles. While analog broadcast signal reception degrades with increasing distance, digital signals follow a “cliff effect,” and beyond a certain level of signal degradation, digital recipients get nothing useful. Some radio and television broadcasters who converted from analog to digital broadcasting reduced their transmitting power. The mapping of digital television signal strength and overall signal quality is essential in ensuring adequate service to a region.

Wireless telephone and data service is an increasingly important part of telecom industry revenues. As the wireless sector matures, retaining customers and minimizing customer turnover can be crucial. Telecom companies need to maintain high-quality signals and telephone reception at minimum cost. Availability of radiofrequency broadcast data quality could help ensure uninterrupted service and promote optimal use of the public broadcast spectrum, a finite resource.

Weather Data: Sensors can measure meteorological data such as air temperature, relative and absolute humidity, air pressure and wind speed. Such measurements are required for accurate weather forecasting. Until recently, weather modeling and forecasting had been constrained by the availability of sufficient computing power. But the advent of inexpensive computing power means that a larger number of data points and a finer modeling grid can now be accommodated to increase the reliability and precision of weather modeling and forecasting. It is also possible to create highly detailed real-time weather data maps. It also permits correlation of large arrays of different meteorological measurements in new ways which could lead to new scientific discoveries.

Pothole Mapping and Road Assessment: Accelerometer sensors permit the assessment of road conditions and mapping of potholes. Eriksson et al. describe the use of an *ad hoc* network of mobile sensors for that purpose. They describe the economic value of a system to identify and locate the frequency, size and proximity of potholes as well as score the overall road quality. Such scoring would provide an objective basis for prioritizing road repairs, given that each neighborhood wants its roads repaired first, and thus such prioritization often is locally contentious. It could also help determine repair costs for a geographic area.

Natural Gas Leaks: Sensors on postal vehicles would permit the identification of locations where gas is escaping from natural gas street mains or other gas pipes. Gas leaks at high concentrations are very dangerous, potentially resulting in an explosion. Smaller or less confined leaks create financial waste and possible health risks. Gas companies already add an odiferous substance (methanethiol), to natural gas as a safety mechanism to help customers detect leaks. Frish, Green, et al. (2005) describe sensors that signal the presence of natural gas. Specialized tracer chemicals (intentional contaminants called taggants), detectable at miniscule levels, have been successfully tested and could increase the effectiveness of a postal-sensor based gas leak detection system.[10]

Noise Profiling: Mobile sensors could record not only sound levels (decibels) but also more complex acoustic features such as signatures/profiles. Noise levels from airports, factories or construction sites could be assessed. Hara and Ozawa (2005) have described the use of mobile acoustic sensing to measure roadway traffic. Sounds beyond human hearing ranges, such as infrasonic and ultrasonic measurements, can also be measured.

Pest Control: Pest control may be possible by dispersing not pesticides but rather insect pheromones to disrupt and confuse the insect courtship and mating processes. This could provide a substantial pest-control benefit for insects of particular concern such as gypsy moths, mosquitoes and the like. The regular traverse of the postal vehicle may make it possible to use tiny, carefully dispensed releases of such material.

Biological Surveys: Biological surveys can be conducted following additional technological development of biologic and chemical sensors. Airborne pollen and bacteria could potentially be counted and classified, as can biological matter found on airborne dust.

Electromagnetic Fields and Scientific Experiments: Postal sensors can provide a useful platform for scientific measurements. For example, Gallo, Landi, and Pasquino (2009) describe the measurement of ambient electric field strengths in urban areas. Exposure to concentrated electric fields can occur near electric equipment, for example, and may impair health and safety. Bicycles have been demonstrated as a way to collect electric field strength data efficiently. Mapping of magnetic fields is also possible. The ability to rapidly acquire and chart a variety of measurements and measurement anomalies linked to specific geographic locations would likely lead to scientific discoveries.

Utility Meter Reading: The idea that letter carriers could read water, gas and electric utility meters is not new. Because many houses are not near their mailboxes, there is no guarantee that letter carriers would always travel close enough to meters on their routes.[11] Furthermore, many utilities have invested in transitioning to automated meter reading, and some utilities have already started to implement such a system. The availability of in-house solutions, the infrequency of meter reading, and the potential reluctance to entrust this important function to another organization (such as USPS) reduces the commercial viability of this application.

Law Enforcement Applications: Law enforcement applications could include detecting illicit laboratories that produce methamphetamine or explosives or locations growing large quantities of marijuana. Mann, Stoeber and Walus (2008 and 2009) describe clandestine drug lab detection using mobile sensors in some depth. Sensors could detect the chemical signatures of those activities. Vehicles could scan and read license plates to flag stolen vehicles. In some areas, local police departments already use police cars to scan license plates.

Photo Imaging and Street Photography: Photo imaging (photography) includes collecting imagery, much in the way Google and Microsoft already collect “street view” photos and weave them together into a seamless panoramic whole, permitting computer-based panning and zooming. Obtaining regularly updated street view photographs could hold significant commercial value in ways we may not yet understand, but also gives pause due to the obvious privacy implications. This may also include taking infrared and/or ultraviolet imagery. Infrared imagery, for example, has value in identifying energy inefficient “hot spots” in buildings.

Being able to retrieve and examine scenes at certain points in time can be helpful. For example, frequent periodic imagery in locations of law enforcement or security interest can provide useful data such as help in solving crimes. Archived imagery could be used for assessing social phenomena (such as parking patterns), or natural phenomena (such as measures of climate change).

4. MARKET ASPECTS

While any vehicle can carry sensors, the use of postal delivery vehicles presents advantages over potential competitors in the areas of economies of scale, network effects, government monopoly restrictions, cost advantages and vertical integration. Taken together, these advantages could impose substantial barriers to entry.

Incumbent postal operators are burdened by a universal service obligation. This requires, among other things, mail delivery at a reasonable frequency to all homes and businesses. Thus, those operators can, within one organization, deploy sensors (or offer access to postal trucks for the purpose of deploying sensors) across the whole or any part of an entire nation.[12] Postal operators also maintain up-to-date address and delivery route data, and the letter carriers are familiar with the daily repeating routes, which usually follow a predetermined sequence. The existence of predictable fixed routes makes it possible to select particular areas for sensing without causing a diversion from the regular route.

Postal trucks take advantage of economies of scale and scope. The incremental cost (relative or absolute) of adding a sensor to travel these routes is relatively small. The postal fleet is associated with a large and well-trained decentralized nationwide labor force that could help coordinate the logistics of sensor placement, software implementation, maintenance and data collection/processing. In the U.S., the government postal trucks have a number of legal and societal protections. For example, USPS benefits from monopolies in letter delivery and access to the mailbox (respectively the private express and mailbox monopolies).

Table 3 identifies fleet characteristics that lend themselves to sensing applications. This comparison indicates that postal vehicles have superior characteristics for this purpose.

Table 3: Assessing Fleet Characteristics Useful for Sensing

Fleet Type	Single National Owner	Regular Routes	Time on the Road	Universal Geographic Coverage	Centralized Maintenance	Geographic Flexibility / Selectivity
Taxis			X			
Police Cars			X		X	
City Buses		X	X		X	
School Buses		X			X	
City Fleet					X	

UPS/FedEx	X	Limited	X	X	X	Limited
Postal Trucks	X	X	X	X	X	X

Thus, there are practical impediments or barriers to other competitors entering the marketplace for sensor services. Incumbent postal operators such as USPS would hold a sustainable competitive advantage, at least nationally. But those barriers are by no means insurmountable, and with sufficient local or regional markets would likely exhibit competition.

It will be crucial to assess and compare the value of these new potential services. Some services have existing substitutes and some do not. Many of the potential applications generate substantial positive externalities, increasing the significance of the public policy issues. Table 4 suggests a set of criteria for assessing the value of particular applications.

Table 4: Criteria for Assessing Application Value

POLICY FACTORS:
The Needs of the Nation
Compatibility with the primary obligations of the postal function
Public Perception and Societal Acceptance
Civil Liberties and Privacy Concerns
Legal Risks
TECHNICAL FACTORS
Technical Feasibility
Ability to Piggyback Multiple Sensors
ECONOMIC FACTORS
Identification of the Customer Base
Revenue and Costs
Availability of Existing Substitute Data Sources
Ability to Accommodate Multiple Customers
Data Brokering and Intellectual Property Monetization

Market segmentation is a means to value data produced. At the outset, potential customers would center on the public sector (government agencies and quasi-public institutions) and the private sector (companies). Eventually, as the internet reduces transactional costs for purchase of data, residential customers and consumers may also form viable markets.

The value of the data (and thus its market) is affected by its form. Some sensing applications generate a continuous, useful data stream. Other applications would be intended to trigger an alarm or alert if an unusual or important event occurs. The applications generating continuous data, should they have sufficient value to potential customers, may be more likely to find buyers and are less likely to require governmental market intervention. Applications that produce an alarm or alert could require more intervention to be viable.

As a first step in evaluating implementation of this concept, it is essential to identify and prioritize for development those applications for which private paying customers exist, and for which the revenue would justify the capital and operating costs and provide net revenues that would justify the effort by the provider(s) and also efforts expended by the customers. Another set of customers are government agencies that would provide funding because of the value of the data provided or negative consequences prevented. Examining these markets one by one could be a way to objectively prioritize these applications. Table 5 identifies ways of identifying possible markets.

Table 5: Ways of Identifying Markets

Request for Information (RFI)	Grant from a Federal Agency
Request for Proposal (RFP)	Open Innovation Model – using an intermediary to facilitate market development and co-create value
Sources Sought Announcement	Evaluation by a Neutral Party
Broad Agency Announcement (BAA)	Nonprofit Organization
Contest / Award / Prize	University Technology Center or Laboratory
Auction	National Laboratory
Creation of Secondary Markets	Business Partners

Two factors suggest that partnering with a private business prepared to assume most of the development risk may be an attractive approach in the United States. One is current limitations on the USPS's access to capital. The second and perhaps more important reason is the postal operators' core competence in delivery operations. Other companies have substantial experience in data sensing, transmission, networking and analysis techniques; they are better situated to design and implement such a system and to market the results of such systems to other clients. Applications with positive externalities that are substantial and valuable compared to cost or excludable benefits may result in market imperfections that necessitate government involvement to avoid waste.

5. CONCLUSIONS

This paper proposes a new category of services beneficial to the public that can be performed by postal operators and their business partners. Sensor emplacement on postal delivery trucks permits efficient, affordable mass collection of geographically-specific data at or near ground level with minimal human participation. The sensors piggyback on a carrier vehicle that already traverses territory in an efficiently routed manner. This makes possible a new category of services for the postal sector that merit further examination.

The first step will be to identify any “low-hanging fruit”, those services for which paying customers exist and provide sufficient margins to provide adequate return on investment. But some services appear to exhibit such strong social benefits that ancillary mechanisms or government intervention may be required to develop the market and avoid wasting or foregoing what may be a valuable resource.

This concept offers some useful benefits. First, it is consistent with the increasing use by private delivery firms such as UPS and FedEx and other large fleets of telematics (i.e. the use of sensors to collect data about vehicle operations) to improve operational efficiency and reduce costs. This concept may provide opportunities for greater use of telematics tools. Second, the data can be collected at very low marginal cost because the trucks are already traversing their assigned routes, and existing sensor/communications technology automates the process of collecting data. Third, the postal operator’s addressing and postal code system is known and accessible to potential customers and permits selectivity and “pre-indexing” of the areas sensed. Finally, there are societal benefits associated with improving weather forecasts, improving the efficiency of pollution controls, or quickly identifying dangerous conditions, among other applications.

Historically, concerns about marketplace competition from a federal agency have caused Congress to limit the types of services the USPS was permitted to provide. If these new services prove to have sufficient value to the nation, it may be worthwhile to reconsider these legal constraints. This highlights the important question of what types of services a governmental or quasi-governmental postal service should be permitted to provide.

Certain sensing activities, such as applications involving law enforcement customers or relating to imaging/photography, tend to trigger substantial and visceral privacy or civil liberties concerns, and would be likely to carry legal risks and could jeopardize public trust.[13] Oversight and safeguards would be essential to anticipate and forestall problems arising from such applications and to reduce public concerns and protect the public interest. One such safeguard could be a review panel to assess, approve and monitor uses of a postal sensor network and to establish procedures and policies for handling of the data collected, and ensure transparency of the process. In short, any sensing by postal vehicles must be consistent with the highly trusted and respected role of a postal service in society.

Postal delivery trucks that go everywhere nearly every day offer a unique platform, and a valuable opportunity to fulfill important additional national objectives. As postal trucks travel the neighborhoods of America (and other nations), they could also collect data important to the country's safety, security, well-being and economic progress.

NOTES

*. The views expressed in this paper are those of the author and do not necessarily reflect the views or policies of the Commission or any individual Commissioner.

1. See Wilson (2005).
2. See, e.g., Tiger Optics Co. (2010).
3. Taylor and Schultz (1996).
4. For homeland security purposes, there may be advantages to sensing using less regular or predictable routes. But there are also some distinct advantages to regular, more predictable routes.
5. See Network World (2010) and Cary (2010).
6. See Cartwright (2008).
7. See Professional Engineering (2009). Pollution from the postal vehicle itself might impede certain measurements. Electric vehicles could be preferable for air pollution measurements.
8. Compounds useful to measure include end products of internal combustion such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO). Other pollutants that might be measured are methane compounds and non-methane volatile organic compounds (NMVOCs) such as benzene, toluene, xylene and 1,3-butadiene. Other potential measurements include ground-level ozone (O_3) levels, ammonia (NH_3), particulate matter, mold, pollen and odors. Measurement of airborne chemicals is accomplished with well-developed techniques, but current measurement techniques for pollen and particulates rely on fairly crude physical methods.
9. See, e.g., Steed and Milton (2008) ("Although we present a study of CO [carbon monoxide], the techniques will be applicable to other environmental properties such as radio signal strength, noise, temperature, humidity and so on.")
10. Kaish, et al. (2000) discuss the use of a family of chemical substances [collectively known as Perfluorocarbon Tracers (PFT's)] to detect leaks in utility gas lines. This patent describes a successful 1988 experiment to detect a leak in a gas line via fixed sensors mounted on telephone poles, demonstrating "the capability for urban and high density tagged chemical detection using conventional PFT sniffing equipment."
11. The location for mail delivery can be far removed from the house where the meter is located, such as in rural areas where the mailbox is stationed at the end of a long road or driveway, or in an area with cluster box units, centralized delivery or general delivery. In many cases, the letter carrier does not drive near the residence or business.
12. USPS operates 196,445 delivery and collection vehicles, according to the 2009 USPS Annual Report, p. 38. In most countries, the postal delivery fleet is the largest vehicle fleet.
13. As an indication of the sensitivities involved, Google, Inc. encountered legal and public relations difficulties in 2010 in several countries when the company disclosed that it had unintentionally collected and retained wireless network data transmitted by businesses and residences as Google's cars were both taking photos and mapping WI-FI signals to permit non-GPS location finding.

REFERENCES

Ariessohn, Peter (2007), Bio-Aerosol Sampling and Detection from an Automotive Platform, Proposal White Paper, Enertechnix, November 29, 2007.

Brown, Bob (2010), Feds Seek to Sniff out Toxic Chemicals with Cellphones, *Network World*, April 13, 2010.

Cartwright, Jon (2008), Mobile Phones Could Spot Dirty Bombs, *PhysicsWorld*, Jan. 31, 2008, viewed at http://physicsworld.com/cws/article/news/32751.

Cary, Bjorn (2010), Cell Phone Detects Hazardous Chemical Spills, *Popular Science*, **277** (1), 32.

Ericksson, Jakob, Girod, Lewis, Hull, Brett, et al. (2008), The Pothole Patrol: Using a Mobile Sensor Network for Road Surface Monitoring. MobiSys'08, June 17-20, 2008, Breckenridge, Colorado.

Frish, Michael B., Green, B. David., et al. (2005), Extended Performance Handheld and Mobile Sensors for Remote Detection of Natural Gas Leaks, Phase II Final Report, May 2005, produced for the Department of Energy under Award No. DE-FC26-02NT41603.

Gallo, Daniele, Landi, Carmine and Pasquino Nicola (2009), Multisensor Network for Urban Electromagnetic Field Monitoring. *IEEE Transactions on Instrumentation & Measurement*; **55** (9) 3315-3322, September 2009.

Hara, Hironori and Ozawa, Shinji (2005), Application of Discrete Wavelet Transform to Traffic Measurement Using Road Environment Sound from Microphone on the Vehicle. *Electronics and Communications in Japan*, *Part 3,* **88** (11).

Kaish, Norman, Frasier, Jay, Otugen, Volkan and Popovic, Svetozar (2000) U.S. Patent 6,025,200, Method for Remote Detection of Volatile Taggant (issued Feb. 15, 2000).

Man, Gabriel, Stoeber, Boris and Walus, Konrad (2009), An Assessment of Sensing Technologies for the Detection of Clandestine Methamphetamine Drug Labs, *Forensic Science International*, **189** (1), 1-13, August 10, 2009.

Man, Gabriel, Stoeber, Boris and Walus, Konrad (2008), Detecting and Identifying Clandestine Drug Laboratories: Sensing Technology Assessment. Technical Report TR-04-2008, University of British Columbia for the Canadian Police Research Center, March 2008.

Milton, Richard A. and Steed, Anthony (2007), Mapping Carbon Monoxide Using GPS Tracked Sensors, *Environmental Monitoring and Assessment*, **124** 1-19.

Professional Engineering (2009), Cyclists Carry Sensors in Project to Monitor City Traffic Pollution, July 8, 2009, **22** (12) 36.

Steed, Anthony and Milton, Richard A. (2008), Using Tracked Mobile Sensors to Make Maps of Environmental Effects. Personal & Ubiquitous Computing, **12** (4) 331-42, April 2008.

Taylor, Richard F. and Schultz, Jerome S. (eds.) (1996), *Handbook of Chemical and Biological Sensors*, Bristol: IOP Publishing Ltd.

Tiger Optics Co. web site, http://www.tigeroptics.com. Description of laser-based cavity ring down spectroscopy at http://www.tigeroptics.com/PAGES/technology.htm (viewed on June 29, 2010).

United States Postal Service (2010), The Challenge to Delivery: Creating the 21st Century Postal Service – 2009 Annual Report. Available at http://www.usps.gov.

Wilson, Jon S. (2005), *Sensor Technology Handbook*, Elsevier/Newnes.