CityEye: Real-time Visual Dashboard for Managing Urban Services and Citizen Feedback Loops

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Abstract

Digital platforms such as smartphones can enable a richer dialogue between the general population and urban maintenance services in real time. Data dashboards may help officials and companies manage urban operations, but often lack relevance, accessibility, or actionability when presented publicly. We review the history of urban dashboards and 311 platforms, and the context of two Spanish cities where these could be combined to engage citizens in monitoring the state of the city. We describe CityEye, a platform that brings together operations, sensor, and citizen feedback data through a web-based dashboard and a service-based mobile application. Greater participation by citizens could allow cities to base maintenance goals on results rather than process, but will require new interfaces and policies for contracting services.

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1. Introduction

Urban infrastructures and services are often described as invisible, not only because they are hidden from plain view, but also because we have learned to take them for granted and rarely notice them daily. However, digital platforms such as smartphones can enable a richer dialogue between the general population and various urban infrastructures and services in real time. For example, social media provides a channel for urban managers to communicate critical service information directly to citizens, while feedback hotlines like 311 and related applications allow citizens to contribute their observations and opinions.

In this paper, we present the technical, informational, and visual design of CityEye, a platform to reduce the distance between citizens and urban service providers, by making the processes of urban maintenance more legible through real-time information dashboards, and by integrating user activated feedback loops through their mobile devices. CityEye aggregates both real-time and asynchronous data generated by service operations, environmental sensors, and citizen feedback, and visualizes these through two interfaces, a "Dashboard" and a "Lens". We assess the opportunities and challenges in deploying CityEye in two Spanish cities based on data availability, existing sensor infrastructure, and relationship between service providers and local government.

2. Methodology

We begin by discussing the history of participatory systems for urban maintenance like Open311, and several case studies of data dashboards specifically designed to present real-time information about city operations. For each dashboard we identify its target audience, information content, and unique aspects of its visual design. We also discuss to what degree these dashboards engage the user in the running of the city.

Following this, we describe the context of Barcelona and Santander in Spain, where we collaborated with public and private officials on ways to engage residents in urban maintenance operations. Each city presented distinct opportunities, challenges, and relationships around the types of and access to real-time data.

We then present a system called CityEye that synthesizes our lessons from the case studies and responds to the contexts of the two cities. We describe its graphical user interface and potential use cases, as well as its underlying technological infrastructure. Finally, we analyze the institutional

changes a system like CityEye would require if implemented in one of the cities.

3. Related Work

3.1 Open311

Offenhuber (2014) reviewed the history of 311-phone systems, which began as dedicated phone lines for citizens to access non-emergency public services. In the early 2000s, cities began to consolidate their various department call centers into 311-phone systems, unlocking two benefits: collecting more and better reports on urban maintenance issues, and aggregating data to map and predict patterns of those issues. When private firms are contracted to perform urban maintenance services, the 311 systems also provide key performance indicators (KPIs) on their responsiveness, as an alternative to direct public inspections.

In parallel, web-based platforms also emerged to collect public requests for urban maintenance, starting with simple citizen-created mash-ups that map pothole photographs, independent websites like "FixMyStreet" and "SeeClickFix", and city-based portals like Boston's "Citizens Connect". These platforms added mobile app interfaces as smartphones grew more popular. The data collected would include location coordinates, timestamps, service categories, and often photographs, making web map mash-ups a common interface for viewing these data online.

Many US cities adopted the "Open311" protocol to standardize the data formats they collect from phone, web, and mobile, making it easier to open, share, and build applications using these data (Desouza & Bhagwatwar, 2012). Open data movements in many cities also offer the opportunity for the public to observe how local governments operate and build innovative applications to visualize, analyze, and apply these Open311 data (Goldsmith & Crawford, 2014).

3.2 GIS, urban maintenance, and public engagement

This strong reliance on mapping and standardized data has brought the Open311 movement closer to the development of geographic information systems (GIS). GIS has been used in many ways for urban maintenance, from decoding addresses into location information (Schwester, Carrizales, & Holzer, 2009), to visualizing and analyzing reports and inventories, to

serving as the backbone for infrastructure data across agencies and contractors (Naphade, Banavar, Harrison, Paraszczak, & Morris, 2011). Asset management systems, such as those used to manage and maintain roads, are a specialized form of GIS used to both streamline operational, day-to-day work and to assign KPIs that measure agency performance overall (Horak, Emery, & Agaienz, 2001).

These tools were traditionally designed for and sold to urban managers, and lacked public-facing interfaces to the information. However, there are examples of urban maintenance operations going public in real-time through maps. For example, major US cities such as Boston, New York, Pittsburgh, and Chicago have released single-issue websites tracking the locations of snow plows and plowed status of streets[1].

GIS is also used to engage the public in bridging their experiences and knowledge with the actions of planners, through the development of softGIS methods (Kahila & Kyttä, 2009). More broadly, public participation GIS (PPGIS) seeks to empower non-expert users to achieve their own goals using GIS tools through user-centered design (Haklay & Tobón, 2003; Schlossberg & Shuford, 2005). These are examples of how geodesign, the use of geospatial analysis and simulation tools to design environments (Goodchild, 2010), can be wielded by those outside of planning professions.

3.3 Urban dashboards

The rise in availability of urban data has encouraged city governments, academia and private companies to invest in ways to analyze, operationalize and communicate the vast amounts of information being created by urban services and operations. To this extent, there's been a growing trend of cities adopting online urban dashboards as instruments in which both public officials and the general public can interact with city data in order to have a better understanding of the operating dynamics of cities (Kitchin, 2014). These dashboards often coexist with a larger information ecosystem that includes service oriented apps for mobile devices and online platforms for e-government, among others.

Preceding the rise of urban dashboards are the concept of cybernetic "control centers," where operators could monitor the behavior of social systems (such as a city or national economy) in real-time and react to stabilize the

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[1] http://snowstats.boston.gov, http://maps.nyc.gov/snow,
http://pittsburghpa.gov/snow/snow-plow-tracker,
http://www.cityofchicago.org/city/en/depts/mayor/iframe/plow_tracker.html

system accordingly. Cybersyn was one such control center manifested in a physical room in the 1970s, designed to allow technocrats to observe data on all aspects of Chile's economy (then under left-wing Allende government rule) from a single chair (Medina, 2006). Many modern cities maintain traffic control centers filled with closed-circuit television screens and data visualizations, through which staff can detect road congestion and accidents; IBM has extended this logic to its massive control room in Rio de Janeiro from which the city can command and control all emergency services (Batty, 2015).

Urban dashboards take this concept out of physical space and make them available from anywhere using personal computer or mobile device screens. This makes it more convenient to share the same information view among a dispersed population, whether they be an expanded group of public officials and technicians, or all residents of the city. These virtual dashboards can help make complex and diverse urban phenomena seem digestible, using raw data visualizations or simplified indicators/benchmarks, but there is an inherent danger of obfuscating or reducing the importance of causes that are not easily sensed or modeled (Kitchin, Lauriault, & McArdle, 2015).
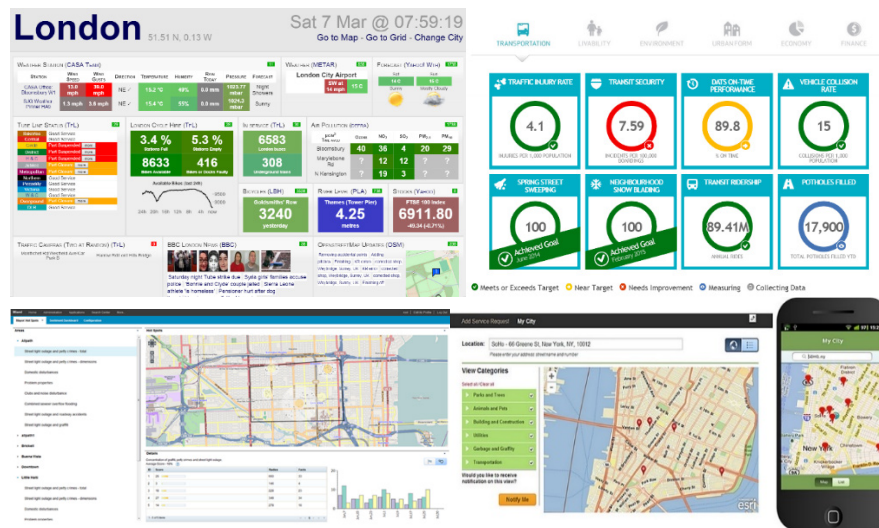

Fig. 1. Dashboard examples. Clockwise from top left: CityDashboard[2], Edmonton Citizen Dashboard[3], IBM IOS citizen feedback applications, IBM IOS executive dashboard ("Smarter cities software," 2015).

CityDashboard[2] is an early, influential project with the goal of "summarizing quantitative data (both officially provided and crowd-sourced) for the major UK cities, in a single screen" (O'Brien, 2012). It shows primarily weather, environmental, transportation, and energy demand in a single screen website, with numerical values in color coded boxes for ease of view. Other data such as camera feeds, news, and OpenStreetMap updates are shown in small screenshots; the dashboard also graphs bike share availability over time, but aggregated across the whole city. It also has a secondary Map view which gives access to specific traffic camera views and sensor readings, but requires users to click each marker to see any information.

While the project attempts to give the user a birds-eye view of what is happening in the city, we see three areas to be improved. First, the overall selection and representation of real-time data is inconsistent, where it is unclear what different colors mean in diverse contexts. Second, the information displayed is in many cases not translated from raw numerical values to a format that might be easier to digest for non-technical users. It is hard for the user to tell if the city is actually performing well, without this context. Third, due to its focus on the most recent reports, it misses the opportunity to give users additional context by visualizing data over recent hours, days, and months. The map view also functions only as a selector, when visualizing data over space could have provided a quicker understanding of traffic patterns overall. Thus, it's not clear if the dashboard is intended for residents or for experts.

Another interesting example is the Edmonton Citizen Dashboard[3], which is part of that city's open data program. The project seeks to "Enable Edmontonians to review and use City data for multiple purposes" (Edmonton, 2015). The citizen is the dashboard's intended user, which is reflected by the way in which integrates data from various official sources and in which it simplifies key performance indicators (KPIs), interaction design, and information selection criteria. The dashboard is structured over six key topics: transportation, livability, environment, urban form, economy, and finance. Each one has additional subtopics; for example, the environmental topic shows KPIs for activities such as sewage cleaning, missed waste collection spots, lot grading inspections, and number of eco-stations user. For transportation the site shows transit ridership, potholes filled, disabled adults transit services levels, and street sweeping.

The Edmonton Citizen Dashboard does a good job of both organizing the data in a hierarchical structured manner, and in representing the data in an easy to understand form. It uses a combination of simplified KPIs, a clear

[2] http://www.citydashboard.org
[3] https://dashboard.edmonton.ca

explanation of what each one represents, and displays them in a clear graphical form that uses consistent color-coding, iconography and fonts. It also shows each KPI in contrast to the city's desired goal to provide performance context. Furthermore, the Dashboard allows users to do a more thorough analysis of the data with a series of interactive tools that graph historical data. Users can then filter the data and access it in raw form. Its main shortcomings are a lack of any real-time operational data; even when it links to social media services, these feedback loops are unrelated to what the user might be observing in the data.

Finally the IBM Intelligent Operations Center for Smart Cities (IOS) allows for citywide monitoring for operations from diverse city agencies, such as emergency response, transportation services, public safety, water, etc ("Smarter cities software," 2015). The platform is geared towards city managers, and as such it aims to be a comprehensive tool that allows for multiple levels and tools for data analysis, along with its integration with urban operations. Although its implementation is dependent on the particularities of each city, its best known instance is the Centro de Operacoes Rio de Janeiro.

The IOS follows a dashboard design that in many ways reflects other solutions derived from the business intelligence and analytics expertise of the company. As such its visual language is primarily integrated graphics and ranking tables, which it complements with spatial mapping of services, GIS analysis, and real-time video feeds. The information is then linked to order processing flows for actionable tickets management. The solution also provides a historical data analysis engine for decision making and planning purposes.

However, the IBM IOS is not an easy-to-access tool; it has a complex interface that still shows many dashboard design principles from the early 2000's which require a steep learning curve from users. It is therefore not suited for general population consumption, who usually interact with the city through service specific applications on mobile phones, call centers, or dedicated city attention points.

4. System Context

In partnership with the company Ferrovial Servicios, we analyzed the Spanish cities of Barcelona and Santander for their potential to open up urban maintenance services information to the public in real-time. For each city, we worked with public officials, researchers, and Ferrovial technicians to identify datasets they could provide through contracted operations with the

city, data-sharing partnerships between public and private institutions, and infrastructural advantages or opportunities.

Table 1. Comparison of Barcelona and Santander urban operations contexts.

	Barcelona	Santander
Waste service information	Dumpster pick-ups (RFID scan), collection vehicle locations, routes with updated itineraries.	Public inspections of KPIs for outdoor trash bins, such as fill level; routes with itineraries.
Road information	Street cleaning vehicle locations, routes with updated itineraries, traffic congestion.	On-street parking availability, traffic congestion.
Environmental sensor information	Environmental sensor data gathered through Sentilo platform.	Environmental sensor data gathered through SmartSantander program.
Citizen feedback apps	"Citizens Postbox" app launched and monitored by City Council, Open311 app implemented by Code for Europe.	Pilot mobile app, implemented by university of Cantabria.
Service areas	Fragmented into districts and service types, served by competing companies.	Citywide contracts for each service type.

Both Barcelona and Santander are self-proclaimed testbeds for "smart city technologies", but with different emphases (Zygiaris, 2013). As a larger city with some power devolved to districts and lieutenant-mayors, Barcelona's efforts have been more fragmented but agile. Waste collection and road maintenance contracts are split between various companies to encourage competition; the companies can experiment with technologies like service vehicle GPS-tracking and waste-bin fill sensors within dense districts like Les Corts. Thus, the available data varies greatly in availability and detail across the city, and the city has had to invest in data standardization projects, like their Sentilo sensor-mapping platform. They have repeatedly redeveloped citizen feedback apps to adhere to new standards and backends, and the challenge is to unify all of the overlapping programs and private technologies into a "city operating system".

By contrast, Santander has invested many resources into deploying fixed environmental sensors throughout the central city, and seeks ways to generate value from these data. All data are collected and handled jointly by the city council and the University of Cantabria, who also developed the citizen feedback application in-house. Contracted urban services are also awarded for the whole city, rather than piecemeal, allowing companies to develop citywide information systems. While this approach has produced more uni-

form sensor networks and consolidated data collection, the resulting applications have failed to generate much interest from citizens or companies operating there. For example, its citizen feedback mobile application shows relatively few users and incident reports.

5. System Design

To address these diverse issues, we propose a data visualization platform called "CityEye" with two main components: the "Dashboard" and the "Lens". The dashboard gives an overview of all incoming real-time data generated by the city – data from urban sensors and other sources such as traffic condition, urban maintenance activities, and incoming citizen reports. It is designed as a data-rich visualization of the whole city, allowing managers to identify and prioritize cross-cutting problems. By contrast, the lens provides a local view, showing a specific set of sensor feeds proximate to the user's location and time. We implement the lens as a smartphone application, designed to provide citizens with more immediate, useful information.

5.1 Dashboard

The data sources included in CityEye can be divided into three categories: (1) data generated by and inferred from environmental sensors, (2) data generated during the provision of services (KPIs), and (3) data generated by citizens. Each dataset either describes the state of the urban environment, or primarily represents human activity.

Environmental sensors, like those deployed in Santander and other smart city projects, can provide us an impartial real-time view of the state of the city. Measurable weather conditions like temperature, humidity, wind, and visibility all affect the hygiene of the city, making prompt trash collection and street cleaning more important at times. Other phenomena like air pollution (such as particulate concentration and NOx level), parking usage, and noise serve as indirect indicators of traffic congestion or crowd gatherings. When collected across many sensors across the city, these data can be visualized to detect patterns and infer service needs or bottlenecks well before they are directly reported. They are also useful to citizens planning events and walking or cycling routes through the city.

Service providers themselves can provide valuable information to this platform. The positions of service vehicles, as measured by GPS and wireless network triangulation, reflect their performance and daily progress.

They also help predict the cleanliness of certain parts of the city, as well as when to expect noise and congestion. The itineraries and actions of service workers can be scrutinized for their relative efficiency, and their own observations can augment the city's ability to keep streets safe. Statistics on trash collected and fuel usage allow both citizens and cities to determine sustainable behavior, and which neighborhoods could stand to improve. When incorporated into the dashboard, these data expose the operational challenges and opportunities of maintaining the streets, parks, waste bins, and other public spaces of the city.

Finally, citizen feedback forms a crucial part of the CityEye dashboard. Complaints, questions, and requests are central to understanding where urban services must go in the short and long term. These can be collected through direct channels, via phone banks, email, and web and mobile applications, but also through social media such as Twitter and Facebook. Social media also allows indirect sentiment analysis, gauging citizen satisfaction with public spaces, which can also guide near and long-term decisions on where to send services and how to incorporate such feedback.

Combining these three data categories into a high-resolution visualization platform can provide a more reliable birds-eye view of the city. By showing citizen reports side-by-side with operations and sensing data, it elevates these concerns to the level of other KPIs.

5.2 Lens

The smartphone app acts as the "lens" of CityEye, and is an important innovation for the transition to smarter urban services. The app will allow citizens to view data from Ferrovial's cleaning and maintenance services in a useful and relevant way, and empower them to communicate their needs or satisfaction with services back to the city and Ferrovial. Our goal is to demonstrate how real-time data, direct actuation by citizens, and urban sensing can help us rethink the possibilities of a core set of urban services, while making them more accessible and human.

The app visualizes both historic and real-time operations data from internal systems for managing service routes and schedules. The user will be able to follow the service routes and service levels related to them, including time of arrival, pick-up, and information on the driver/vehicle/service in progress; garbage weight and recycling composition; as well as historic and future service requests. The app will also show the citizens real-time environmental information from sensors (e.g. environmental noise, CO, CO_2, air particles, light levels, cameras) mounted on Ferrovial's service trucks, transforming them into a flexible and dynamic sensing platform for the city.

Rather than show visualizations overlaid on the entire city as in the dashboard, the lens focuses on graphs and predictions for service in the user's vicinity.
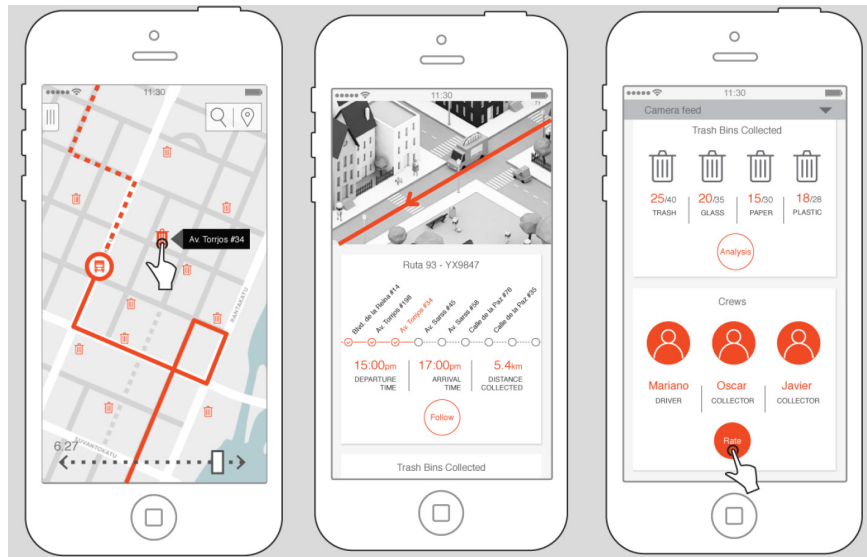

Fig. 2. Interaction mock-up screens for Lens application, highlighting operations data most relevant to user in place, over time.

Most important, the platform will have tools to integrate citizens' feedback into the service. In this way, the app closes and humanizes an interaction loop between users and what is often perceived as an anonymous service. Users could use the app to directly report a problem (such as an overflowing bin or a messy area), request a future service, or even post satisfaction comments with the service; these interactions will be publicly visible through the interface in order to foster social interaction around topics like recycling and street safety. The proposed interactions would take full advantage of the smartphone's capabilities, and will integrate geo-location and multimedia data captured from the devices. Finally, the app would also have a push notification module that will keep citizens informed in real time on service level conditions and relevant information to the users.
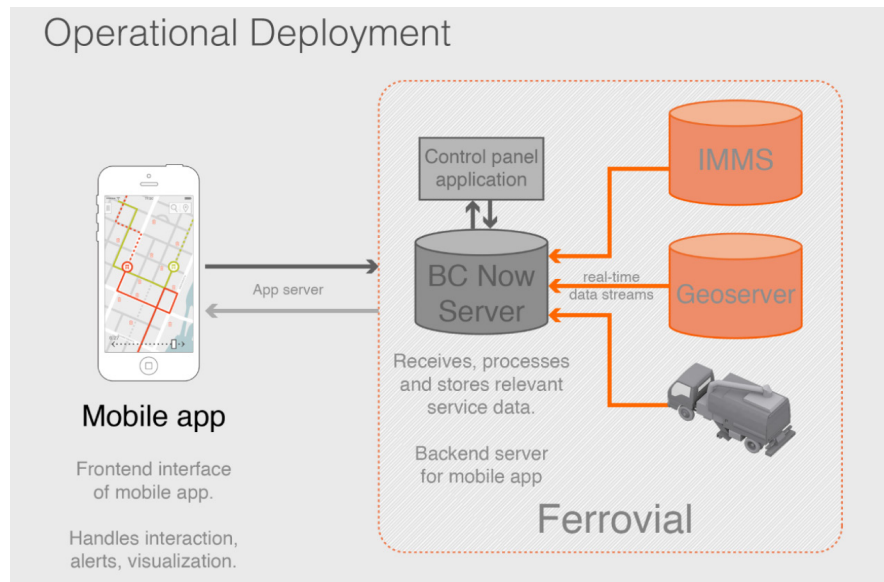
Fig. 3. Interaction between "lens" mobile application, servers, and operations data in Barcelona implementation.

Ultimately, the citizen can use the app for a variety of purposes, including:

- Monitor the processes of urban maintenance in their neighborhoods.
- Check environmental conditions and urban activity for personal decisions; for example, the choice of public transportation depends on factors such as traffic condition, heat, or pollution levels.
- Deploy incident reports or requests, which become publicly visible.

Individuals working for the city and the service provider can use the system to:

- Estimate the demand for a specific urban service depending on human activity or environmental factors.
- Monitor citizen-submitted incident reports to inform decisions regarding service provision or urban repair.
- Engage the public in the processes of urban maintenance, creating appreciation of these often-invisible services.

Through the smartphone app, CityEye brings the power of the city dashboard down to the ground level of the city, where data can be directly applied to improving quality of life. In this way, the lens becomes a two-way communication channel, linking individual citizens, workers, and officials

to the larger task of maintaining the city. Over time, the depth of this interaction will yield more valuable insights, and the benefits in reduced cost and improved service will be shared by all.

6. Discussion and Conclusion

6.1 Additional data sources

One possible shortcoming of the three proposed data streams is that they do not capture all human activity in the city. Such data, however, are highly important to inform and support citizens and service providers. We therefore suggest including additional data sources, such as:

- Real-time traffic information
- Real-time public transportation schedules and usage
- Additional sensors that capture pedestrian activity in public space – these could include Bluetooth radios that count the number of active mobile devices carried by pedestrians, a proven proxy for overall pedestrian flow
- Sensors that capture information relevant for urban maintenance – for example, sensors capturing the amount of material inside waste bins
- Local wind sensors and local amount of traffic
- Water quality testing in drains, sewers, and public waterways

However, since such information is not usually included in urban operations dashboards, developing an adequate visual language is an important next step for CityEye.

6.2 Conclusion

For urban service providers, CityEye could allow for more agile operation of urban services, making it possible to quickly react to real-time events and demands rather than static performance targets. Local governments will be able to track the progress of services and needs of citizens, spending fewer resources to maintain a clean, responsive public realm. Citizens will also be able to witness this improved transparency, and may come to demand it in the same way that public transportation and traffic data have become ubiquitous; real-time awareness may also drive more useful feedback to the city.

However, those outcomes depend on several prerequisites: governments and service providers must share data in real-time; these shared data must be standardized in breadth and depth, if not format; visualizations must be

readable and useful to non-experts; and service providers must be swiftly responsive to citizen reports, in order to close the feedback loop and encourage further public participation.

6.3 Acknowledgments

References

Batty, M. (2015). A perspective on city dashboards. *Regional Studies, Regional Science*, *2*(1), 29–32.

Desouza, K. C., & Bhagwatwar, A. (2012). Citizen apps to solve complex urban problems. *Journal of Urban Technology*, *19*(3), 107–136.

Edmonton, C. of. (2015, March 6). Open Data :: City of Edmonton. Retrieved March 7, 2015, from http://www.edmonton.ca/city_government/initiatives_innovation/open-data.aspx

Goldsmith, S., & Crawford, S. (2014). *The Responsive City: Engaging Communities Through Data-smart Governance*. John Wiley & Sons.

Goodchild, M. F. (2010). Towards geodesign: Repurposing cartography and GIS? *Cartographic Perspectives*, (66), 7–22.

Haklay, M., & Tobón, C. (2003). Usability evaluation and PPGIS: towards a user-centred design approach. *International Journal of Geographical Information Science*, *17*(6), 577–592.

Horak, E., Emery, S., & Agaienz, A. (2001). Key performance indicators for road infrastructure asset management by a roads agency in a large local authority. In *Proceedings of 20th South African Transport Conference. July16–20*. Retrieved from http://www.profemery.info/papers/KPI_2001.pdf

Kahila, M., & Kyttä, M. (2009). SoftGIS as a bridge-builder in collaborative urban planning. In *Planning support systems best practice and new methods* (pp. 389–411). Springer.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal*, *79*(1), 1–14.

Kitchin, R., Lauriault, T. P., & McArdle, G. (2015). Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards. *Regional Studies, Regional Science*, *2*(1), 6–28.

Medina, E. (2006). Designing freedom, regulating a nation: socialist cybernetics in Allende's Chile. *Journal of Latin American Studies*, *38*(03), 571–606.

Naphade, M., Banavar, G., Harrison, C., Paraszczak, J., & Morris, R. (2011). Smarter Cities and Their Innovation Challenges. *Computer*, *44*(6), 32–39.

O'Brien, O. (2012, April 23). CityDashboard. Retrieved from http://oo-brien.com/2012/04/citydashboard/

Offenhuber, D. (2014). Infrastructure legibility—a comparative analysis of open311-based citizen feedback systems. *Cambridge Journal of Regions, Economy and Society*, rsu001.

Schlossberg, M., & Shuford, E. (2005). Delineating" public" and" participation" in PPGIS. Retrieved from https://scholarsbank.uoregon.edu/xmlui/handle/1794/1343

Schwester, R. W., Carrizales, T., & Holzer, M. (2009). An examination of municipal 311 system. *International Journal of Organization Theory and Behavior*, *12*(2), 218–236.

Smarter cities software. (2015, March 7). [CT253]. Retrieved March 7, 2015, from http://www-03.ibm.com/software/products/nl/intelligent-operations-center

Zygiaris, S. (2013). Smart city reference model: Assisting planners to conceptualize the building of smart city innovation ecosystems. *Journal of the Knowledge Economy*, *4*(2), 217–231.