



CROWDSOURCING TRANSPORTATION SYSTEMS DATA

February 2015





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Report Title: Crowdsourcing Transportation Systems Data

MDOT REQ. NO. 1259, Connected and Automated Industry Coordination
Sequence D 02 Crowd Sourced Mobile Applications

February 11, 2015

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ACKNOWLEDGMENTS

This document is a product of the Center for Automotive Research and Parsons Brinkerhoff, Inc. under a State Planning and Research Grant administered by the Michigan Department of Transportation.

This document benefited significantly from the participation of representatives at transportation operations centers (TOCs). The authors thank the following individuals for their valuable contributions:

- Lee Nederveld from the MDOT Statewide TOC (STOC)
- John Abraham, Adam Merchant, and Jon Coleman from the Macomb County Department of Roads (MCDR)
- Suzette Peplinski and Paul Arends from the MDOT West Michigan TOC (WMTOC)
- Ahmad Jawad of the Road Commission for Oakland County (RCOC)
- Dayo Akinyemi, Sarah Gill, Marjorie Zabel, Walter Ison, and Aaron Raymond of the MDOT Southeast Michigan TOC (SEMTOC)
- Meghan Butler of the MDOT Bluewater Bridge TOC (BWBTOC)

EXECUTIVE SUMMARY

Crowdsourcing involves leveraging the combined intelligence, knowledge, or experience of a group of people to answer a question, solve a problem, or manage a process. Opportunities for crowdsourcing have greatly increased with the broad adoption of internet-connected devices, especially smartphones. Leveraging this network of connected people and devices for transportation system management is an important opportunity.

The term crowdsourcing is applied in common usage to several dissimilar processes. To establish a clear scope for this report, we have organized crowdsourced transportation data applications into four categories:

1. Third-party Aggregated Crowdsourced Data
2. Social Media for Public Engagement
3. The Internet as a Sensor
4. Dedicated Platforms for Transportation System Management

THIRD-PARTY AGGREGATED CROWDSOURCED DATA

Many transportation agencies already obtain aggregated crowdsourced data through contracted third-party commercial providers, most often for traffic speed and vehicle-count information. Commercial providers offer clearly defined products and services, customer support, and professional expertise. Such arrangements allow agencies access to proprietary data that would be otherwise difficult to obtain. Agencies may also use third-party data to avoid tedious data cleaning and management tasks. Purchasing additional types of third-party data is a future possibility.

SOCIAL MEDIA FOR PUBLIC ENGAGEMENT

Many agencies have experimented with leveraging internet-based social networks to obtain public feedback regarding the condition of the transportation system and performance of the agency. Americans spend more online time using social networks than any other online activity. The number of people a transportation agency could potentially reach through existing social media platforms is substantial. Agencies can simultaneously disseminate information, gather additional information from system users, and take advantage of instantaneous unmediated information sharing on the platform.

THE INTERNET AS A SENSOR

Broadly defined, a *sensor* is any device that takes a measurement and converts it into readable data. Recent research in transportation demand modeling has investigated the concept of using of the internet itself as a virtual sensor capable of providing valuable, actionable data. Research has suggested that open traffic data can be used to obtain network traffic speed estimations that are equal to or better than traditional sensors. Additionally, internet-as-a-sensor methods may be able to predict the impact of special events, such as festivals and sporting events, on the transportation system.

DEDICATED PLATFORMS FOR TRANSPORTATION SYSTEM MANAGEMENT

Crowdsourced data collection using purpose-built dedicated applications is rapidly gaining momentum within multiple industries. Transportation agencies and others have already deployed a wide range of custom-built applications to collect transportation system information. The potential applications of crowdsourcing will continue to diversify in the future as applications, wireless networks, and other technologies continue to evolve.

INTEGRATING CROWDSOURCED DATA INTO EXISTING AGENCY PRACTICES

Crowdsourced data comes in a large number of formats, which presents a challenge for integrating such data with legacy systems. Agencies wishing to leverage crowdsourced data must establish data-intake processes that interpret and distribute the data appropriately. An efficient data-intake process will allow agencies to use crowdsourced data in real-time for operations and maintenance, as well as to store data for future uses such as research and planning activities. Agencies will select and employ specific approaches for data integration based on the format of the raw data that an agency obtains, and the goals that the agency has in using data. Clearly stated goals are critical when designing a data-integration strategy.

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1 INTRODUCTION

Crowdsourcing involves leveraging the combined intelligence, knowledge, or experience of a group of people to answer a question, solve a problem, or manage a process. The term, ‘crowdsourcing,’ is relatively new, but the basic idea is not.¹ Crowdsourcing is a natural solution to problems inherent in the management of complex systems.² As social, political, technological, and other dimensions of society have grown increasingly complex and connected, crowdsourcing has emerged as a powerful tool in the management of various systems and has the potential to become even more useful in the future.

The range of problems that can be addressed through crowdsourcing has greatly increased in recent years with the broad adoption of internet-connected devices, especially smartphones. Over half of all adults in the United States

CROWDSOURCING: LEVERAGING THE COMBINED INTELLIGENCE, KNOWLEDGE, OR EXPERIENCE OF A GROUP OF PEOPLE TO ANSWER A QUESTION, SOLVE A PROBLEM, OR MANAGE A PROCESS.

now own a smartphone.³ By 2018, the figure will exceed 75%.⁴ Smartphones combine cellular communication with a computer processor and customizable software. Today’s smartphones include multiple communication and data transfer methods, an array of built-in sensors, adaptable architecture, and a powerful processor.

Thousands of software applications are available to smartphone users.

The combination of personal computers, smartphones, and other mobile devices has led to pervasive and frequent connectivity for much of the population. Leveraging this network of connected devices for transportation system management is an important opportunity. This report discusses several

¹ Galton 1907.

² Most modern political scientists would agree that democracy (crowdsourced political will) is superior to oligarchy (centrally managed political will). Also, most modern economists would agree that capitalism (crowdsourced market pricing) is superior to centrally managed economies. Modern socioeconomic systems are more complex than described in any pure idealized form, but the systems that have proven to be most stable over the last few centuries have generally involved a significant degree of crowdsourcing.

³ 58% of American adults own a smartphone as of January 2014. <http://www.pewinternet.org/fact-sheets/mobile-technology-fact-sheet/>, accessed January 2015.

⁴ Additionally, about 15% of smartphone users are under 18, implying that well over 75% of drivers will likely be smartphone users by 2018. <http://www.emarketer.com/Article/US-Smartphone-Usage-Nears-UK-Levels/1010730>, accessed June 2014.

approaches that transportation agencies can use to leverage crowdsourcing techniques for transportation system planning, management, and operation.

1.1 SCOPE OF THIS REPORT (WHAT IS CROWDSOURCING?)

For purposes of this report, crowdsourcing is defined as, “leveraging the combined intelligence, knowledge, or experience of a group of people to answer a question, solve a problem, or manage a process.” This definition must be further refined to clearly establish the scope of this report.

Establishing a working definition of crowdsourcing is complicated because the word is applied in common usage to a wide variety of activities and processes. Yet many activities that would seem to meet any definition of crowdsourcing are often not thought of as such. For example, any research project that includes a *literature review* leverages the combined intelligence of the authors of previous works; however, literature review is not generally thought of as crowdsourcing. Presumably, literature review and similar research tasks are not considered crowdsourcing because the contributors of knowledge are passive in the process. Nonetheless, many activities that *are* commonly considered crowdsourcing also involve extracting data from passive providers. For example, using connected vehicle technology (probe vehicle data) to estimate traffic speeds is a commonly cited example of crowdsourced transportation data. However, submitting traffic speed data from probe vehicles is usually a passive activity for the person generating the data. Furthermore, that person might not even be aware that he or she is generating data.

A logical justification for considering use of probe vehicle data as crowdsourcing while omitting the literature review process is not obvious. CAR’s research makes it clear that it is very difficult to develop a definition for crowdsourcing that is both internally consistent and consistent with common usage of the term. In short, what is and what is not included within the scope of crowdsourcing, as popularly conceived, appears to be somewhat arbitrary.

For purposes of this report, we have attempted to limit the scope to data that transportation industry practitioners popularly consider to be ‘crowdsourced transportation data’ in common usage. We have also included novel or innovative approaches to acquiring useful data for transportation agencies that meet our original definition.

Specific applications that some might classify as crowdsourcing, but are omitted from our scope are listed in Table 1, below.

TABLE 1: APPLICATIONS OUTSIDE REPORT SCOPE OF CROWDSOURCING

NOT Included in Scope	Reasons
Agency Fleet Vehicles equipped with AVL and/or sensors	Agency-owned fleet vehicles that are equipped with data acquisition systems are leveraging agency manpower and resources—not the public ‘crowd.’ While equipped vehicles might be a novel and innovative means of data collection, it is not crowdsourcing.
Data Collected by Agency Employees in the Course of their Job	Some have suggested that data collected by agency employees via mobile apps on smartphones or tablets should be considered crowdsourcing. However, this is simply a more efficient way for agency employees to do their jobs, similar to sensor-equipped fleet vehicles (above). It is not leveraging the experience or knowledge of the <i>crowd</i> .
Traditional Traffic Sensors	Traditional traffic sensors such as cameras, inductive loops, microwave vehicle detection stations (MVDS), etc., can provide data similar to that provided by probe vehicles (e.g., average speed), but such in-situ sensor systems are not traditionally considered to represent crowdsourcing.
Data Collected via Traditional Media	Transportation agencies can use information provided by traditional media outlets such as news reports, weather forecasts, etc. These uses are not traditionally considered to be crowdsourcing.
License Plate Reidentification	Origin-destination, speed, and other types of traffic data can be collected by automatically reading license plates at various points in the network. While this leverages the collective experience of public motorists, it is not popularly viewed as crowdsourcing and thus is not included in our scope.
Bluetooth/Wi-Fi Reidentification	Many consider Bluetooth/Wi-Fi reidentification to be an example of crowdsourcing. This has been placed outside of our scope because: (1) Bluetooth/Wi-Fi reidentification does not provide data that cannot be provided by traditional methods (i.e., license plate reidentification, MVDS, etc.) that are not generally considered crowdsourcing, (2) Bluetooth/Wi-Fi reidentification require the agency to deploy roadside equipment—similar to traditional sensors, and (3) People submitting data are not volunteering data and are generally not aware they are being tracked.
Traditional Literature Review and Research	Not popularly considered crowdsourcing.
Traditional Public Meetings and Comments	Not popularly considered crowdsourcing, particularly when done to meet regulatory requirements and/or when participation is low.

When the applications listed in Table 1 are omitted from the scope of crowdsourcing, the remaining applications for transportation can be grouped into four categories, as shown in Figure 1, below.

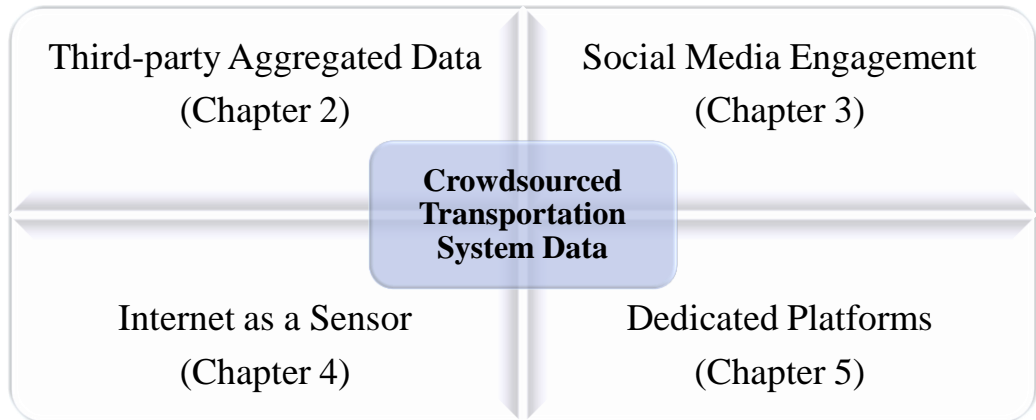


FIGURE 1: CATEGORIES OF CROWDSOURCED TRANSPORTATION DATA

The remainder of this report describes these four categories of crowdsourced transportation systems data, provides specific examples of crowdsourcing implemented in practice, and discusses how agencies have implemented (or could potentially implement) crowdsourced data into existing practices (Chapter 6).

2 THIRD-PARTY AGGREGATED CROWDSOURCED DATA

Many transportation agencies already obtain crowdsourced data through contracted commercial providers. Commercial providers offer clearly defined products and services, as well as customer support and professional expertise. Such arrangements allow agencies access to proprietary data that would be otherwise difficult to obtain and allow them to avoid tedious data cleaning and management tasks. Agencies can also avoid dealing with sensitive personally identifiable information by receiving only aggregated data from providers.⁵

2.1 HISTORICAL AND REAL-TIME TRAFFIC DATA

Transportation agencies often contract third-party vendors to obtain data for historical and live traffic conditions. This often includes average speed and vehicle counts. MDOT currently obtains traffic data for planning and management purposes through a third-party vendor, HERE (a traffic data and mapping service offered by Nokia). Most traffic-information vendors use some combination of proprietary probe-vehicle data, proprietary sensor data, public sensor data, and other publically available information.⁶ While third-party traffic data *is* an example of transportation agency use of crowdsourced data, such contractual arrangements are an established practice and need not be discussed further here.

2.2 CELLULAR GEO-POSITIONING DATA

Transportation planners often use multi-day travel data to understand use of the transportation system and develop long-term planning priorities.

Traditionally, this is done by utilizing citizen-volunteers to answer surveys, keep a travel journal, or carry a GPS tracking device. These methods are generally expensive, have a limited sample size, and are prone to errors.⁷

The broad adoption of cell phones and connected devices provides an opportunity for objective measurements of peoples' movements and use of the transportation system. Aggregated location data provides a potential source of travel behavior data. Even at the cell level (i.e., geographic data identifying a

⁵ Dennis, Cregger, and Hong 2014.

⁶ Liou et al. 2013; Cambridge Systematics 2012; Thiagarajan et al. 2009.

⁷ Wang, Chen, and Ma 2013; Abdulazim et al. 2011; Lee and Williams 2013.

connected device at a particular cell tower), planners may use cell data to gain insight into broad mobility patterns throughout a population.

Another advantage of this method is that cellular travel studies can continue long-term or indefinitely, allowing researchers to investigate evolving patterns of mobility trends in an area.⁸ Datasets available through emerging technologies, such as connected vehicles, might further improve the quality and level of detail that is readily accessible by agencies through third-party providers.⁹ Any partnerships with traffic data or cellular service providers must consider the privacy rights of consumers/citizens.¹⁰

Crowdsourcing in Practice

Commercial Traffic Data Providers

It has become common practice for transportation agencies to contract with private sector data providers that use crowdsourcing (probe vehicles) to obtain historical and real time traffic information. Popular providers include:

- Inrix <<http://www.inrix.com/>>
- HERE <<http://here.com/>>
- Cellint <<http://www.cellint.com/>>
- Telenav <<http://www.telenav.com/>>
- TrafficCast <<http://trafficcast.com/>>
- TomTom <http://www.tomtom.com/en_gb/licensing/products/traffic/>

⁸ Wang, Chen, and Ma 2013.

⁹ An alternative approach that would bypass necessity of partnering with cellular providers is to develop a dedicated app that can be downloaded by volunteers (e.g., Abdulazim et al. 2011; Safi et al. 2015). This is further discussed in Chapter 5.

¹⁰ Dennis, Cregger, and Hong 2014.

3 SOCIAL MEDIA FOR PUBLIC ENGAGEMENT

AMERICANS SPEND MORE TIME USING SOCIAL NETWORKS THAN ANY OTHER ONLINE ACTIVITY.

Most transportation agencies already use social media in some way. For example, MDOT's Facebook page, which has over 9,000 'likes,' is updated regularly with event announcements, construction information, photos, and interesting facts.¹¹ MDOT's Twitter feed, which has over 23,000 followers, is actively monitored and responsive to questions and concerns.¹² MDOT also has a YouTube, Instagram, and Google+ presence.¹³ Digital communications such as these social media outlets are likely to continue becoming embedded into the daily fabric of contemporary life. As shown in Figure 2, Americans spend more time using social networks, on average, than any other online activity. The communication potential of these sites represents extensive possibilities for improving the planning, management, and operations of the transportation system.

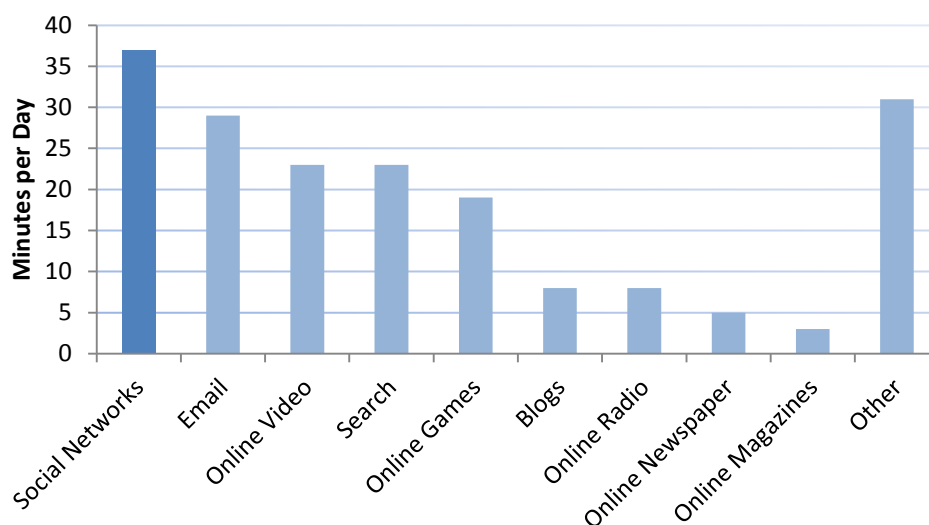


FIGURE 2: AVERAGE MINUTES PER DAY SPENT WITH ONLINE ACTIVITIES IN THE U.S. IN 2013¹⁴

¹¹ <https://www.facebook.com/MichiganDOT> last accessed November 2014.

¹² <https://twitter.com/MichiganDOT> last accessed November 2014.

¹³ <https://www.youtube.com/michigandot>; <http://instagram.com/mdotpicoftheday>, <https://plus.google.com/110889497392032235057/about>

¹⁴ Source: "Data Point: Yes, Email Still Eats Up a Good Chunk of Your Day." *WSJ Digits*. May 20, 2014. Accessed May 2014 at: <http://blogs.wsj.com/digits/2014/05/20/data-point-yes-email-still-eats-up-a-good-chunk-of-your-day/#>.

3.1 COLLECTION AND DISSEMINATION OF SYSTEM STATUS INFORMATION

Public agencies are legally and ethically obligated to involve the public in agency activities.¹⁵ Social media provides an opportunity to streamline and improve public relations and communications. Many agencies have already deployed social media strategies with positive results. For example, MDOT routinely posts information to its Facebook and Twitter pages and actively monitors both, responding to comments and complaints relatively quickly and helpfully. Additionally, each MDOT region has its own Twitter feed and provides information about events and projects with local impact.¹⁶ The MDOT Bluewater Bridge TOC (BWBTOC) also maintains a Twitter feed. MDOT's Facebook and various Twitter accounts are currently working as an effective and efficient conduit for public dialog.

Social media outlets such as Twitter can be extremely useful for communicating system status during special events and disruptions. Agencies can simultaneously disseminate information, gather additional information from system users, and take advantage of instantaneous unmediated information sharing on the platform.

One weakness of a social media communication strategy is that users of social media networks skew demographically younger and more educated than the general population.¹⁷ But these demographic disparities will reduce as adoption of digital technologies continues. By 2018, more than 75% of drivers in the U.S. will be smartphone users.¹⁸ However, to reach the remaining population of travelers, transportation agencies will have to continue to disseminate information through traditional means for constituents that lack access to mobile devices. A multi-platform approach to information dissemination is necessary to reach the widest possible cross-section of the public.

Another weakness of using social media platforms is that such networks often evolve or fall out of use. Agencies should not consider any social media engagement strategy as permanent. The transient nature of these platforms

¹⁵ Dennis, Cregger, and Hong 2014.

¹⁶ http://www.michigan.gov/mdot/0,4616,7-151-9620_67093-261456--,00.html, accessed May 2014.

¹⁷ Mitchell and Guskin 2013; Chan and Schofer 2013.

¹⁸ <http://www.emarketer.com/Article/US-Smartphone-Usage-Nears-UK-Levels/1010730>.

will require agencies to periodically assess if a particular outreach strategy is effective.

Crowdsourcing in Practice

New York MTA Use of Twitter During Hurricane Sandy

Transportation agencies along the east coast of the United States used Twitter to communicate with the public during Hurricane Sandy in October 2012 using the hashtag, #Sandy.¹⁹ In the New York region, the Metropolitan Transit Authority (MTA) saw its Twitter account gain tens of thousands of new followers at this time as system users sought up-to-date information on the public transit system. The MTA's Twitter feed (@mta) now has more than 137,000 followers and remains an active line of communication to the public.

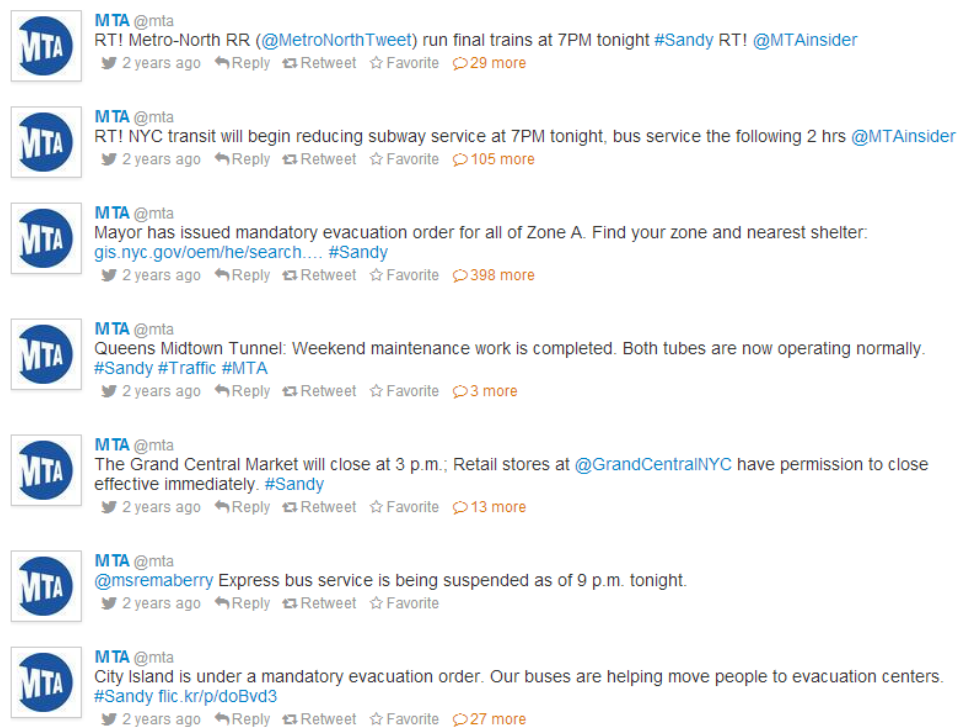


FIGURE 3: EXAMPLE OF @MTA TWITTER FEED DURING HURRICANE SANDY²⁰

¹⁹ The use of hashtags to discuss specific events is a valuable feature of Twitter. Using the #Sandy hashtag allowed MTA to reach Twitter users who were not @mta followers but were seeking information related to the emergency. During the Detroit storm of August 11, 2014, MDOT's Metro Detroit area Twitter feed (@MDOT_MetroDet) frequently tweeted information regarding highway conditions, but missed an opportunity to amplify the message by using the hashtag that emerged to identify the event, #Detroitflood.

²⁰ Source: topsy.com (Twitter logging service)

3.2 PLANNING AND PROJECT PRIORITIZATION

Transportation planners are often tasked with setting priorities for distributing limited funds on an extensive range of potential projects. In Michigan, the distribution of funding is largely determined by Act 51 of 1951 and Federal transportation funding regulations. While the regional distribution of transportation funding is somewhat predetermined by Act 51, the selection of projects requires a combination of formal strategic planning and public participation.

Federally funded projects administered by MDOT are programmed through the State Transportation Improvement Program (STIP).²¹ A documented public participation process is a required component of the STIP. MDOT's public participation plan includes the dissemination of information via press releases, focus group sessions, newsletters, brochures, public comment forums, and newspaper postings.²² Yet, the last STIP received only twelve public comments—half of which were from people representing corporate or government interests.²³

THE MICHIGAN 2014-2017 STATE TRANSPORTATION IMPROVEMENT PROGRAM (STIP) DRAFT RECEIVED ONLY TWELVE PUBLIC COMMENTS.

As shown in Figure 2, Americans spend a lot of time using social media. The vast majority of this time is on large and established platforms (e.g., Facebook, Twitter, Snapchat, etc.). The raw number of people a transportation agency could potentially reach through existing social media

platforms is substantial. Additionally, the increasing popularity of platforms such as Facebook allow for increasingly broad demographic representation.²⁴ Some planners have already successfully experimented with engaging constituencies via these platforms to supplement and support traditional public participation.

²¹ http://www.michigan.gov/mdot/0,1607,7-151-9621_14807_14808---,00.html. An STIP is federally required for all states to receive federal highway funds.

²² MDOT Draft STIP FY 2014-2017. Accessed May 2014 at: http://www.michigan.gov/documents/mdot/MDOT_Draft_2014-17_STIP_document_430052_7.pdf.

²³ MDOT FY 2011-2014 STIP Public Review and Comments Summary Report, accessed May 2014 at: http://www.michigan.gov/documents/mdot/MDOT_FY11-14_STIP_Comments_Summary_Report_338493_7.pdf.

²⁴ Evans-Cowley and Griffin 2011.

One potential problem with using social media for public participation is the potential to lose control of the discussion.²⁵ While it is important to allow a range of views, un-moderated discussions often become un-focused, un-constructive, and divisive. Forums that allow easy and anonymous participation often devolve into unstructured arguments and personal attacks. Considering this, A few agencies have begun utilizing custom-developed transportation planning and prioritization internet and mobile applications, as subsequently discussed in section 5.7 of this report.²⁶

Crowdsourcing in Practice

City of Austin Social Networking and Planning Process (SNAPP)

Through a grant from the Federal Transit Administration, the City of Austin collaborated with partners to create the Social Networking and Planning Project (SNAPP). SNAPP was charged with piloting, tracking, and evaluating the use of an integrated array of tools to build relationships through online social networking to increase the quality and quantity of participation as part of the Austin Strategic Mobility Plan. The SNAPP program resulted in “more than 9,000 relevant comments and approximately 6,300 participants.”²⁷



²⁵ For example: Ford, Dana. “#D’oh! NYPD Twitter Campaign Backfires.” *CNN.com*. April 24, 2014. Accessed June 2014.

²⁶ *infra.* pp. 29.

²⁷ Evans-Cowley 2011.

4 THE INTERNET AS A SENSOR

Broadly defined, a *sensor* is any device that takes a measurement and converts it into readable data. Recent research in transportation demand modeling has investigated the concept of using the internet itself as a ‘virtual sensor’ capable of providing valuable, actionable data.²⁸ The potential to use the internet as a virtual sensor likely will increase as more connected devices are adopted by consumers.²⁹

SENSOR: A DEVICE THAT TAKES A MEASUREMENT AND CONVERTS IT INTO READABLE DATA.

The continued increase of connected people and devices can provide agencies access to completely new types of data. Internet-as-a-sensor applications are just beginning to be adopted in select industries. These applications often employ new techniques in data-mining and machine learning. Agencies that are early adopters have the opportunity to use internet-as-a-sensor methods to develop innovative solutions to transportation systems management.

4.1 MINING SOCIAL MEDIA DATA TO SUPPLEMENT PUBLIC PARTICIPATION

Public participation in the transportation planning process is essential to ensure that the needs and concerns of affected constituencies are considered. Unfortunately, traditional public participation methods (e.g., community meetings) often result in low community involvement and over-representation of special interests.³⁰ Online forums can largely alleviate this issue, as discussed in section 3.2. Nonetheless, a large percentage of constituencies remain difficult to engage in a meaningful way. These include people that are too busy, uninformed, or disengaged to participate in any official forum.

Many of these people, while not easily reachable by planning agencies, are nevertheless active on social media and might even use these forums to discuss transportation-related issues with their network of peers. New paradigms of open data and big data analysis are making it possible to scan a

²⁸ Pereira, Rodrigues, and Ben-Akiva 2011.

²⁹ Internet-connected devices are often described as comprising the ‘Internet of Things (IoT).’ A prime example of sensors embedded in IOT devices are the continued advances in connected vehicles, flood control/water quality sensors, smart meters/disconnects, or traffic signal controllers.

³⁰ Misra et al. 2013.

wide range of internet sites in search of posts that relate to a particular topic or agency.³¹ Such methods are in generally early stages of development, and they might require complex methods of data mining and sentiment analysis.³² As these methods continue to develop, transportation planners should consider these techniques to supplement traditional methods of public participation.

4.2 USING OPEN TRAFFIC DATA

Most transportation departments monitor the condition of their road network with fixed roadside sensors and traffic cameras. As of 2013, MDOT maintained approximately 456 traffic cameras and 488 microwave vehicle detector sites (MVDS).³³ The installation cost of this network is in the tens of millions of dollars, and the network requires millions of dollars of maintenance each year.³⁴ Future crowdsourcing methods and open data availability may enable agencies to reduce the cost of such traditional sensor networks.

TRAFFIC SPEED ESTIMATION

When MDOT and other transportation departments began deploying sensor and camera networks to monitor traffic, there was no viable alternative to collecting such data. Prior to deployment of these sensor systems, the only way of getting real-time traffic data was through eyewitness reports and traffic helicopters. Today, real-time comprehensive performance data is available through proprietary probe-vehicle networks, many of which make traffic data available for free over the internet.

Google was the first company to launch an application programming interface (API) for its online map in 2005. This API can now be used to reference Google's live traffic data.³⁵ There are now similar APIs from Bing Maps, MapQuest, HERE, TomTom, and others. One study found that travel time estimation provided by these internet sources is within 95% of the measurements by traditional sensor networks (MVDS).³⁶ The internet data

³¹ Russell 2013.

³² Pang and Lee 2008.

³³ MDOT and CAR 2013.

³⁴ MDOT and CAR 2013.

³⁵ <https://developers.google.com/maps/> accessed November 2014.

³⁶ Morgul et. al 2013 compared open traffic data to fixed MVDS station readings. Bing Maps and MapQuest APIs were used for the study because these services allow unlimited queries

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was also generally found to be less prone to errors and gaps in data provision.³⁷ The study concluded that this “virtual sensor methodology comes with almost no additional cost while the quality of the data obtained is quite satisfactory compared to physical sensors.”³⁸

As traffic data service providers continue to expand probe vehicle networks, the data provided via web and mobile APIs is expected to become increasingly accurate. These data could possibly supplement or even replace existing sensor networks. That said, it remains unclear to what extent free internet traffic data providers use public data provided by transportation agencies.³⁹ The quality of the data could suffer if transportation agencies sunset operation of existing traffic sensors. In order for a stand-alone probe vehicle network to provide real-time data on the entire traffic network with accuracy, probe penetration rates of at least 10% are required. With a 20% penetration rate, the traffic model provided by probe vehicles can be “very accurate.”⁴⁰ The penetration rates of proprietary probe vehicle networks are difficult to determine due to the proprietary nature of probe vehicle networks, but they are likely much less than 10%. To supplement the relatively low penetration rates for a given probe network, commercial traffic data providers supplement their probe network data by fusing probe data with other sources such as fixed-sensors and open internet sources.⁴¹ Additionally, data providers might not continue to supply free traffic data in the future. If public agencies did not provide open traffic data, then the market price of such data likely would increase and end the practice of making traffic data publically available at no cost to the end-user.

(...continued from previous page)

for free. Other services, such as Google Maps, cap the number of traffic time queries for free accounts, but do offer paid commercial accounts unlimited queries.

³⁷ Morgul et al. 2013. This study was conducted on a section of divided highway in New Jersey. These findings may not be generalizable, for example, to low volume and rural roads.

³⁸ Morgul et al. 2013; Kurkcu, Morgul, and Ozban 2015.

³⁹ For example, MDOT sensor data is combined with probe vehicle data from HERE. HERE relays the fused data to MiDrive and also markets the data commercially. <http://mdotnetpublic.state.mi.us/drive/>. It is reasonable to assume that proprietary traffic data often incorporates data from such public systems.

⁴⁰ Nagle and Gayah 2013. This figure assumes that probe data is not supplemented with other data such as historical trends or fixed-sensor data.

⁴¹ This represents a non-direct way of combining probe-vehicle networks, resulting in better accuracy than any single probe vehicle network could provide.

Crowdsourcing in Practice: Crowdsourced Traffic Information

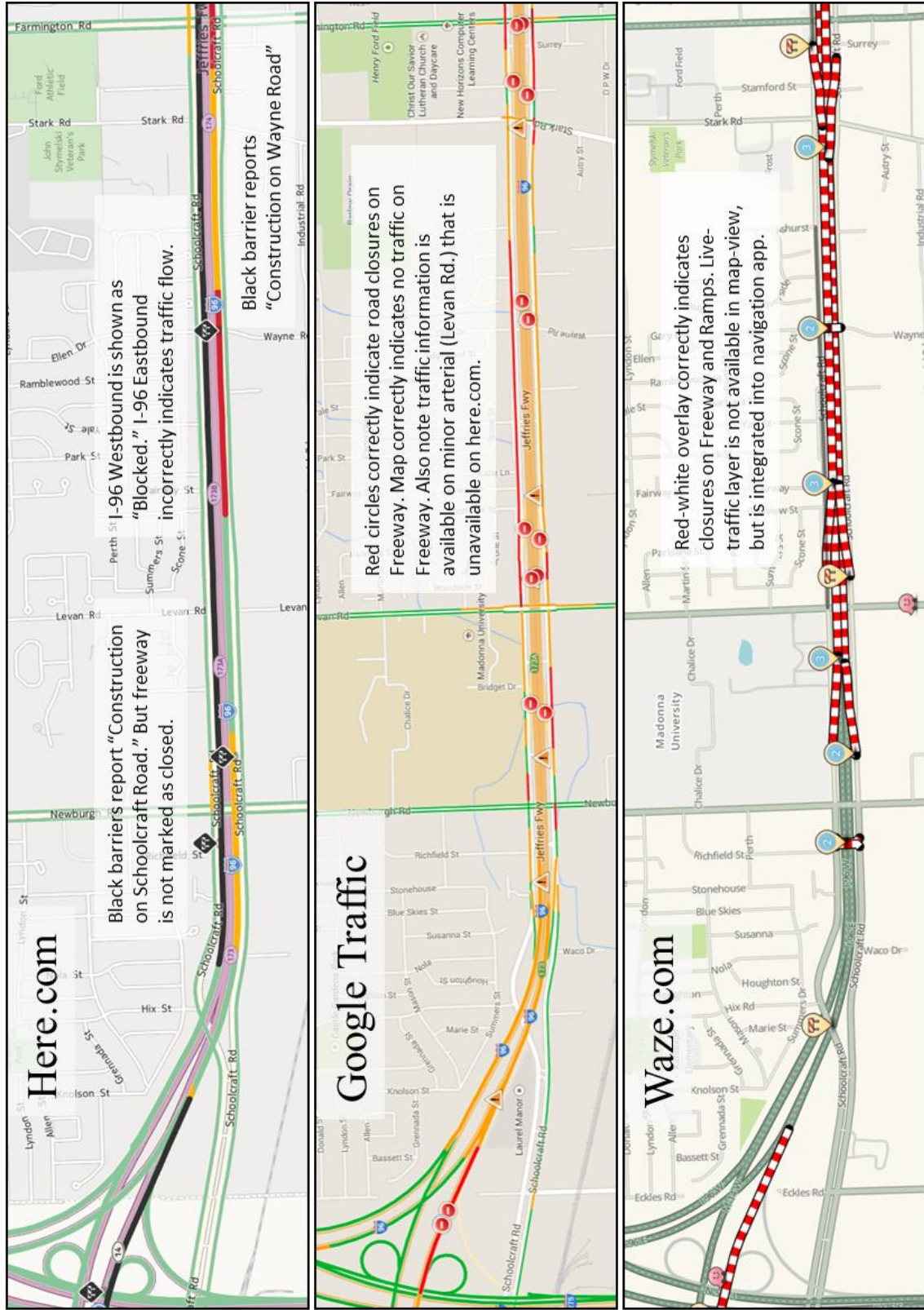


FIGURE 4: COMPARISON OF WEB-REPORTING OF FREEWAY CLOSURE ON HERE.COM, GOOGLE TRAFFIC, AND WAZE.COM, MARCH 23, 2014

Much of the value provided by contracted third-party data providers is the data fusion, analysis, and information packaging necessary to turn raw data into traffic information useful to a transportation agency. However, a transportation agency could potentially develop the ability to perform these tasks in-house.

Many commercial services also log traffic data, allowing identification of trends. For example, Google Maps provides “typical” traffic conditions based on historical data. Figure 5 shows that afternoon rush hour traffic on I-94 East typically shifts from free-flow conditions to severe congestion due to traffic entering the highway from the State Street interchange.⁴²

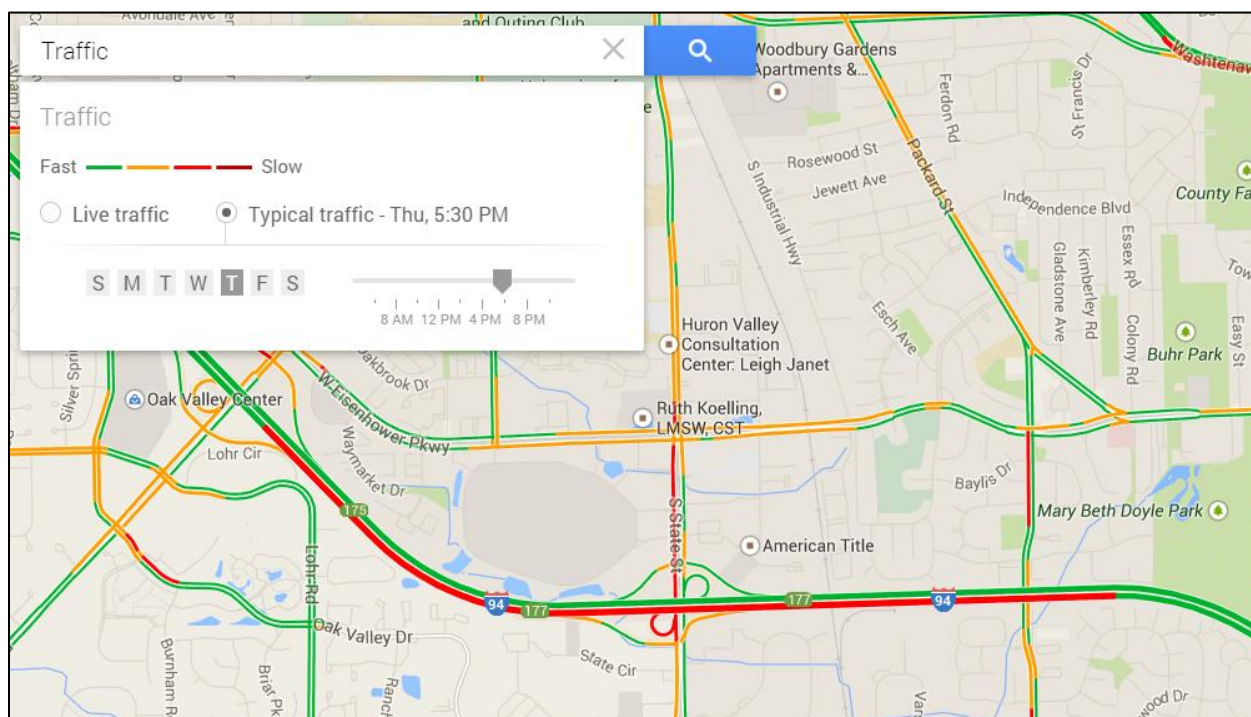


FIGURE 5: GOOGLE MAPS TRAFFIC SHOWING “TYPICAL” TRAFFIC CONDITIONS AT 5:30 PM ON THURSDAYS ON I-94 AT STATE STREET INTERCHANGE IN ANN ARBOR

ACCIDENT AND EVENT REPORTING

Transportation operations centers typically receive event information from field observations or police dispatch. This method of data collection leads to some events not reported to TOCs in a timely manner, or at all. For example, while MDOT TOCs are integrated into Michigan State Police (MSP) dispatch

⁴² This pattern has been informally confirmed by CAR analysts. (CAR offices are very near this interchange.)

programs, if local (i.e., county or municipal) police respond to an accident, they might never report it to MDOT.

Internet-as-a-sensor methods may supplement traffic incident detection.⁴³ The Waze platform, in particular, offers one potential solution to this problem. Users of the mobile app are able to report events that impact traffic conditions in real-time, as well as remove reported events after they have cleared.⁴⁴ Many TOCs are experimenting with using Waze to monitor traffic conditions, either through formal partnerships or simply through the free web-based platform.⁴⁵

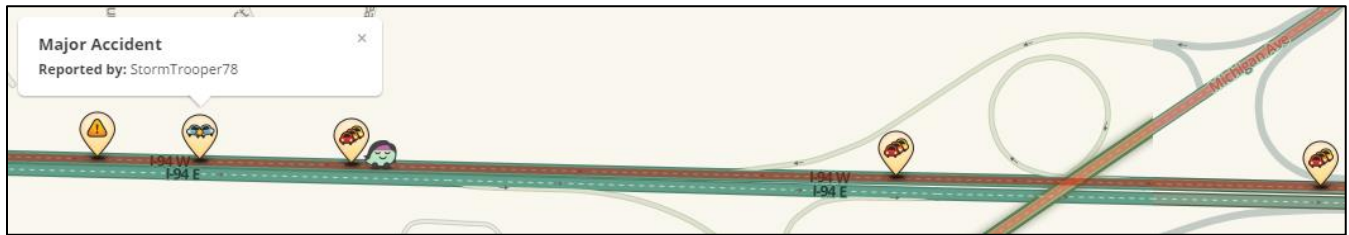


FIGURE 6: WAZE WEB INTERFACE SHOWING CROWD-SOURCED REPORTING OF TRAFFIC CONDITIONS ON I-94 DURING WEATHER EVENT ON NOVEMBER 19, 2014

TRAFFIC INFORMATION DISSEMINATION

Many of the platforms discussed in this section (Google Maps, Waze, MapQuest, etc.) are primarily information-dissemination platforms. Travelers use these platforms to receive turn-by-turn navigation directions and live traffic information. From a user-perspective, the creation of crowdsourced data is a secondary activity. This report concentrates mostly on the information-gathering aspect of crowdsourcing platforms. However, transportation agencies are equally concerned with providing the traveling public with accurate and timely information. Contributing data to these free and publically available platforms could be an efficient and effective means of distributing information to the traveling public—effectively outsourcing traffic information dissemination.

Drivers value information related to travel time along a route, and may choose alternate routes based on such information.⁴⁶ Many transportation departments have deployed Dynamic Message Signs (DMS) as part of a traveler information strategy. DMS can be costly to install and maintain, and have

⁴³ Kurkcu, Morgul, and Ozbay 2015.

⁴⁴ MDOT's MiDrive platform has been updated to allow crowdsourced reporting.

⁴⁵ Florida DOT is one agency that has formalized data-sharing agreements with Waze.

⁴⁶ Kitamura and Nakayama 2007.

many weaknesses as a strategy to convey useful information to travelers. For example, given that DMS are placed at fixed locations, they may not be placed as to provide actionable information for specific incidents. Some drivers might not notice DMS or have their vision blocked by a large vehicle. Finally, it is simply difficult to provide information that is relevant to all system users, yet actionable for individuals. It is unclear how DMS impacts traffic flow.⁴⁷

Crowdsourcing in Practice

FDOT – Waze Partnership



The Florida Department of Transportation (FDOT) has provided Waze with the credential to access the third-party data feed from FDOT's 511 system and Waze has already utilized the feed to post information on their application with appropriate attribution. In addition to information from the third-party data feed, FDOT is supplying Waze with information on construction, location of toll facilities, special events, speed limits, evacuation routes, emergency shelters, etc. Waze provided FDOT with access to their feed, and FDOT is in the process of analyzing the data feed to develop an interface between Waze and FDOT's traffic management software.⁴⁸ With this partnership, FDOT is not only obtaining data from the crowdsourcing platform, but is efficiently disseminating travel information tailored to the routes and locations of individual Waze users.

When DMS gained popularity as a traveler information strategy, it was one of the few methods for drivers to obtain real-time traffic data, beyond radio-broadcast traffic reports.⁴⁹ Today, more than half of drivers have smartphones, and this percentage is expected to increase to more than 75% by 2018.⁵⁰ Any driver with a smartphone has access to real-time traffic information, and can

⁴⁷ A literature review on the efficacy of DMS did not find empirical data regarding the impact of DMS on system performance (Haghani et al. 2013; Chen et al. 2011; Murthy, Lu and Rajaram 2011; Hernandez, Chui, and Yang 2010, Al-Deek et al. 2009, Vasudeval et al. 2008, Hadi et al. 2008). CAR analysts were unable to locate any research that observed measured improvement in system performance as a result of DMS deployment. The assumptions regarding DMS in existing literature are generally based on user surveys or traffic modelling software.

⁴⁸ Glotzbach 2014.

⁴⁹ There are also 511 services that provide traffic information via phone in many locations.

⁵⁰ Additionally, many vehicles now come with an embedded navigation devices that offers live traffic conditions.

run free navigation applications that automatically re-route based on traffic conditions.⁵¹ Table 2 provides a list of popular smartphone navigation apps.

In addition to smartphone apps, an increasing number of vehicles have factory-installed cloud-enabled navigation systems that provide similar information. Transportation agencies should consider the benefit-to-cost ratio of installing and maintaining DMS when most drivers have access to more complete, convenient, and personalized information with them inside their vehicle.⁵²

TABLE 2: SMARTPHONE NAVIGATION APPS WITH LIVE TRAFFIC INFORMATION⁵³

App	Cost	Notes
Apple Navigation	free	Proprietary map and traffic data. iOS only.
Co-Pilot HD	\$15+ \$10/yr	From ALK Technologies, Ltd. Traffic data by Inrix.
Garmin Viago	\$2+ \$20/yr	Unique 3D views and lane choice guidance. Traffic data from HERE.
Google Navigation	free	Proprietary map and traffic data. The world's most popular smartphone app.
Inrix	\$10	Inrix Traffic data. Google Map data.
MapQuest	free	Owned by AOL. Uses OpenStreetMap. Traffic from Tomtom/Inrix.
MotionX GPS Drive	\$10/yr	Traffic data from Trafficast.
NAVIGON	\$50+ \$20/yr	Owned by Garmin, maps and traffic data by HERE.
Scout	free	By Telenav, Inc. Uses OpenStreetMap. Allows crowdsourced user reports. Proprietary traffic data.
Sygie	\$40+ \$15/yr	Offline maps only. Traffic data provided by Tomtom/Inrix.
TomTom	\$39+ \$20/yr	Traffic data from Inrix.
Waze	free	Proprietary map and traffic data. No offline option. Crowdsourced traffic hazard reporting and map editing.

⁵¹ While such applications require heavy battery use on the phone, in-vehicle chargers are available that can keep smartphones perpetually charged regardless of usage. As shown in Figure 4, open crowdsourced traffic data are often more accurate than data provided by commercial services.

⁵² MDOT and CAR 2013.

⁵³ Costs are believed to be accurate as of July 2014. Most apps with a one-time download cost are charging for static a digital map. Thus, cellular connectivity is not needed for navigation (but is needed for live traffic). Map updates may cost extra.

Crowdsourcing in Practice

Connected Navigation and Route Planning using Crowdsourced Traffic Data

A primary draw for users of some connected navigation platforms is that the applications provide route guidance using real-time traffic information and crowdsourced event data. Waze places a particular emphasis on crowdsourcing. Not only do Waze users passively send traffic speed information, but Wazers can actively report road closures and hazards, and even update the Waze basemap. Figure 7 (left) shows route options provided with estimated travel times across town in Ann Arbor during a large special event (Ann Arbor Art Fair). Figure 7 (right) shows road-closures reported by Waze users. Closed roads are automatically circumvented in route calculations.

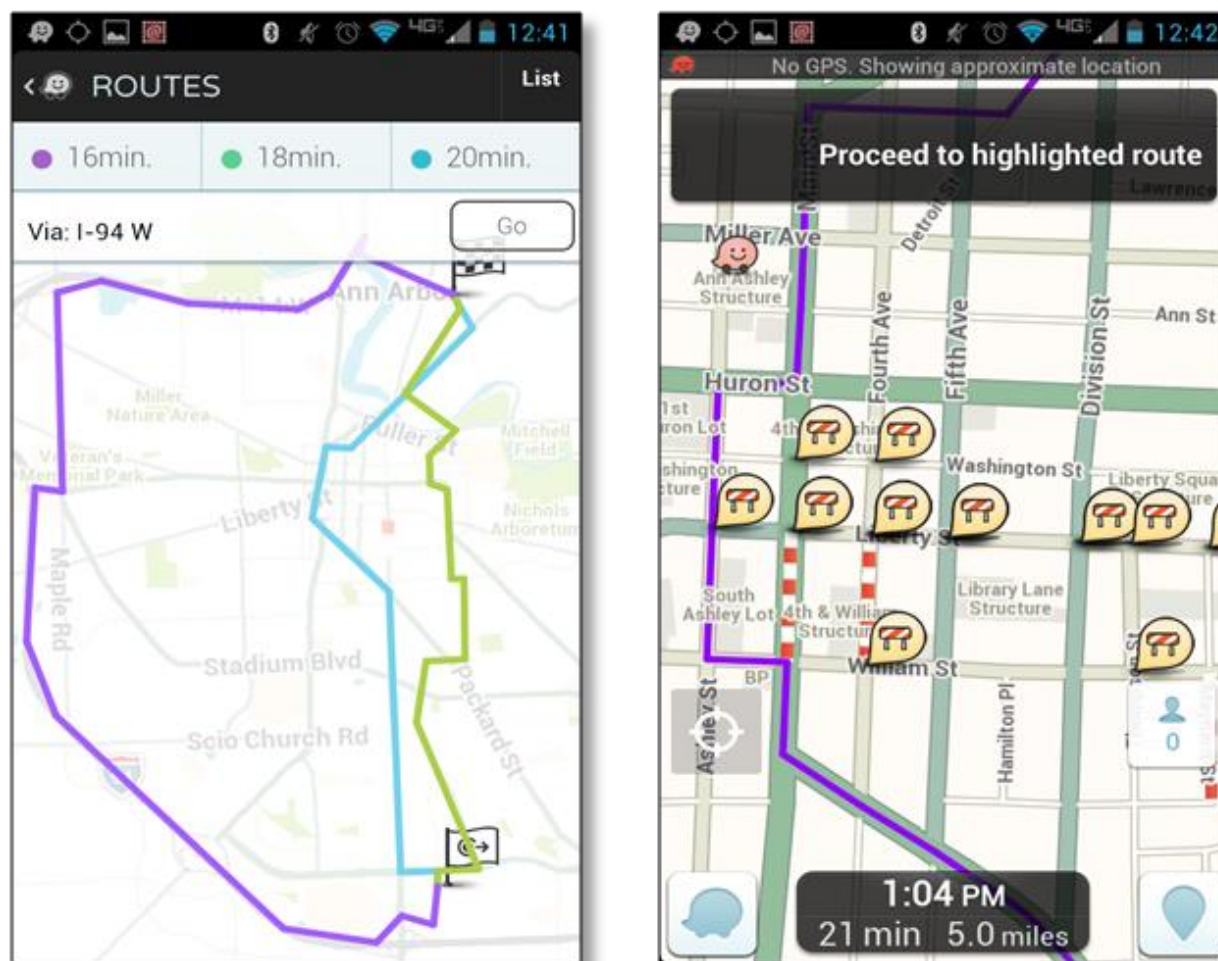


FIGURE 7: WAZE NAVIGATION APP FOR SMARTPHONES SHOWING ROUTE OPTIONS WITH PREDICTED TRAVEL TIME AND CROWDSOURCED ROAD CLOSURE INFORMATION DURING SPECIAL EVENT

4.3 PREDICTING TRAFFIC SPIKES FROM SPECIAL EVENTS

Special events (e.g., sporting events, concerts, festivals, etc.) can draw tens of thousands of participants, and often create severe traffic congestion. Event participants often arrive and depart an event within a very short time-window, leading to acute overcapacity of the local transportation network.

Transportation agencies often employ special tactics to deal with event traffic. This can include increasing public transportation provision, deploying traffic-control officers, providing informational signage, adjusting signal timing, and re-routing traffic.⁵⁴

Special event traffic can stress the transportation system, even with planning and preparation. Traffic gridlock in an event area can make it difficult for emergency vehicles to travel, pollute an area with vehicle exhaust, and generally inconvenience local residents and businesses. Extended gridlock due to special events can cause social and economic harm.

IRREGULAR SPIKES IN TRAFFIC-DEMAND CAN BE PREDICTED BY SCANNING LIVE-STREAMING DATA FROM SOCIAL MEDIA AND OTHER INTERNET SOURCES.

Most large events are planned in advance and have a predictable impact on the transportation system. In locations where special events are a regular occurrence (i.e., around stadiums, concert venues, etc.), transportation agencies regularly coordinate with event planners and are familiar with traffic mitigation strategies. By their nature, some events make it

difficult for transportation systems operators and managers to predict the traffic impact, such as when attendance numbers and other relevant factors are not known in advance. For example, a sporting event with a popular visiting team can draw an unusually large crowd and disproportionate portion of that crowd might be traveling a long distance by vehicle. Furthermore, many irregular special events have localized transportation demand impacts that are difficult to predict and often happen without coordination with relevant traffic control agencies.

Recent research suggests irregular spikes in traffic demand can be predicted by scanning live-streaming data from social media and other internet sources.⁵⁵ While such data is unstructured and difficult to parse, models that

⁵⁴ Zhanh et al. 2009.

⁵⁵ Pereira, Rodrigues, and Ben-Akiva 2011.

incorporate machine learning for prediction have successfully increased the accuracy of traffic and transportation demand prediction models.⁵⁶

Tools that process internet data are widely available as APIs or open-source software. The methods of integrating such data in traffic prediction models could potentially be very complex.⁵⁷ One conceptualization of such an architecture is shown in Figure 8. However, even very simple tools can be effective. One study used only Twitter data to improve short-term event-related traffic volume predictions by 24%.⁵⁸ Our research has not identified any transportation agencies currently utilizing this method in practice.

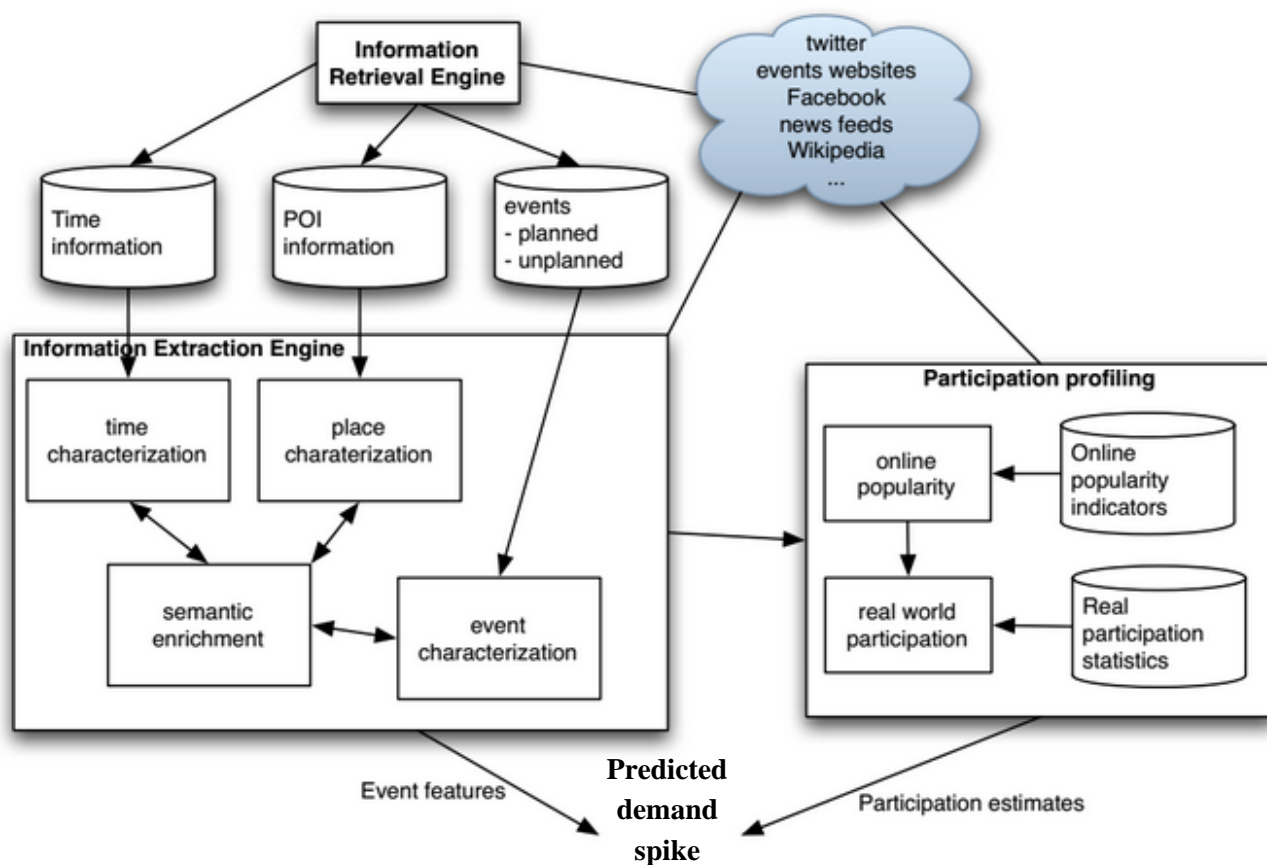


FIGURE 8: EXAMPLE OF PROPOSED INTERNET DATA MINING ARCHITECTURE FOR TRANSPORTATION SYSTEM DEMAND SPIKE PREDICTION⁵⁹

⁵⁶ Ni, He, and Gao 2013.

⁵⁷ Pereira, Rodrigues, and Ben-Akiva 2011.

⁵⁸ Ni, He, and Gao 2013.

⁵⁹ Source: Pereira, Rodrigues, and Ben-Akiva 2011.

5 DEDICATED PLATFORMS FOR TRANSPORTATION SYSTEM MANAGEMENT

Previous chapters have described ways in which data from existing platforms may be re-purposed for management of the transportation system. This chapter will discuss the potential to use *dedicated* crowdsourcing platforms, where the data generated by the platform is created specifically for transportation system management. These applications can utilize the phone's built-in GPS, accelerometers, camera, and other sensors to allow the agency to collect a wide variety of information. The potential applications of crowdsourcing will continue to diversify in the future as technology and communications continue to improve. Dedicated crowdsourcing apps covered in this chapter include:

- Automated Vehicle Location for Public Transit
- Pavement Condition Data Collection
- Bicycle Travel and Infrastructure Data
- Parking Management
- Origin-Destination Studies
- Environmental Data Collection
- Planning and Project Prioritization

5.1 AUTOMATED VEHICLE LOCATION FOR PUBLIC TRANSIT

Transit agencies often install automated vehicle location (AVL) devices on transit vehicles to assist in operations. Additionally, many agencies make vehicle locations available to the public in real-time either through a dedicated website, or publishing General Transit Feed Specifications (GTFS) in real-time to application developers.⁶⁰

While effective, AVL systems can be expensive and incur maintenance costs. The popularity of transit apps like Google Transit, Moovit,⁶¹ and RideScout⁶² creates the possibility of utilizing the transit system users who use these apps

⁶⁰ <http://maps.google.com/help/maps/mapcontent/transit/live-updates.html> accessed July 2014.

⁶¹ <http://www.moovitapp.com/> accessed July 2014.

⁶² <http://inthecapital.streetwise.co/2014/05/20/dc-tech-ridescout-launches-transit-app-chicago/> accessed July 2014.

as vehicle location devices. If sufficient user participation can be obtained, transit agencies could essentially outsource public transit vehicle tracking to riders—with significant cost savings.⁶³

Crowdsourcing in Practice

Tiramisu Transit-vehicle Tracking App

Researchers at Carnegie Mellon University have created a smartphone app that allows transit agencies to crowdsource public transit vehicle location.⁶⁴ While Automatic Vehicle Location systems can be expensive to install and maintain, the app—Tiramisu—negates the need for embedded AVL systems by using transit users’ smartphones. When a user selects a destination, Tiramisu shows a list of transit options available with predicted arrival times. The predictions are based on historical data as well as real-time data sent by riders on the vehicle. Once aboard, riders can also use Tiramisu to report the occupancy rate of the bus, monitor upcoming stops, and report issues and general experiences.⁶⁵

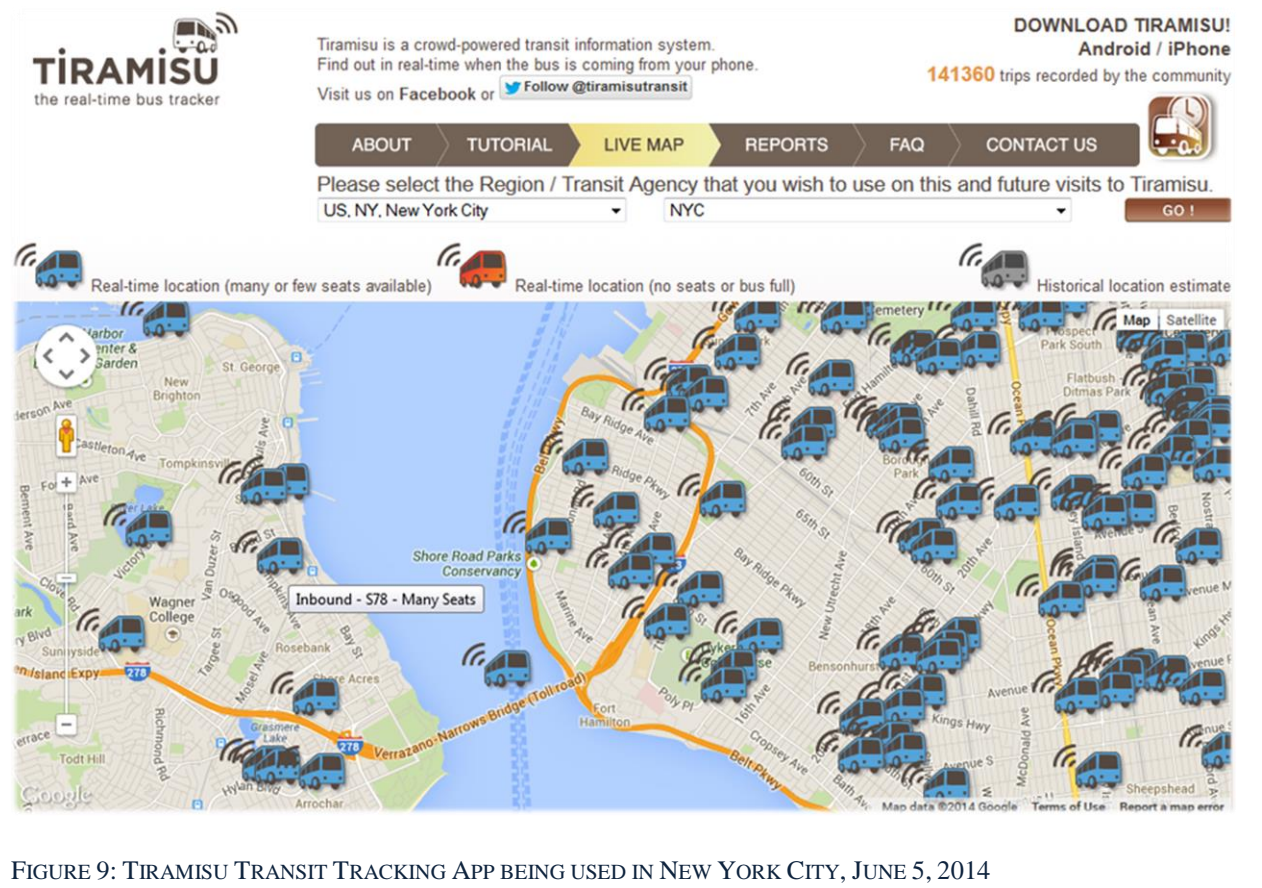


FIGURE 9: TIRAMISU TRANSIT TRACKING APP BEING USED IN NEW YORK CITY, JUNE 5, 2014

⁶³ Steinfeld et al. 2010.

⁶⁴ <http://www.tiramisutransit.com/> accessed June 2014.

⁶⁵ Misra, et al. 2013.

5.2 PAVEMENT CONDITION DATA COLLECTION

Many transportation agencies, including MDOT, already crowdsource data on potholes and road issues by allowing system users to report issues via phone or web applications. But this method is not effective at providing a timely and accurate system-wide perspective. Many research organizations and transportation agencies are pursuing low-cost pavement condition measurement using connected vehicles or devices. Sensors embedded in smartphones have been shown capable of detecting potholes, rough pavement, and low friction areas.⁶⁶ MDOT has previously investigated the possibility of using probe vehicles to obtain pavement condition data automatically.⁶⁷ The pursuit of this approach could allow MDOT to incorporate data from the public. The main difficulty in this approach likely would be recruiting enough drivers to use the app.⁶⁸

Crowdsourcing in Practice

Street Bump Smartphone App

Boston is testing a dedicated mobile app—Street Bump—to identify potholes using the smartphone's accelerometer and GPS. Recorded bumps are uploaded to a back-end server for analysis. Algorithms are used to identify likely potholes from the sum of bump events. Identified potholes are then submitted to the City via Open311 and are scheduled to be fixed.⁶⁹



FIGURE 10: STREET BUMP SMARTPHONE APP⁷⁰

⁶⁶ Dennis et al. 2014, pp. 20-25.

⁶⁷ Dennis et al. 2014, pp. 18-19.

⁶⁸ Dennis et al. 2014, pp. 20, 27-28.

⁶⁹ <http://www.cityofboston.gov/doi/apps/streetbump.asp>, accessed June 2014.

⁷⁰ Source: <http://www.fastcoexist.com/1679322/street-bump-a-smartphone-app-automatically-tells-the-city-when-you-drive-over-potholes>, accessed June 2014.

5.3 BICYCLE TRAVEL AND INFRASTRUCTURE DATA

Transportation planners have successfully used crowdsourcing as a method of gathering data on the use and utilization of bike infrastructure. Cycle trips make up a low percentage of overall trips and are difficult to capture with traditional vehicle-counting devices. Municipalities that have developed crowdsourced mobile applications to collect data on bicycle infrastructure use include San Francisco, Minneapolis, Atlanta, and Austin.⁷¹

Crowdsourcing in Practice

Minnesota DOT Cyclopath Wikimapping Project

The Twin Cities of Minneapolis and St. Paul are widely considered among the most bicycle-friendly cities in the U.S. Contributing to this effort is Cyclopath, a crowdsourced bicycle systems map hosted by the MnDOT. Available in the Twin Cities since 2008, MnDOT has recently expanded the map statewide.⁷²

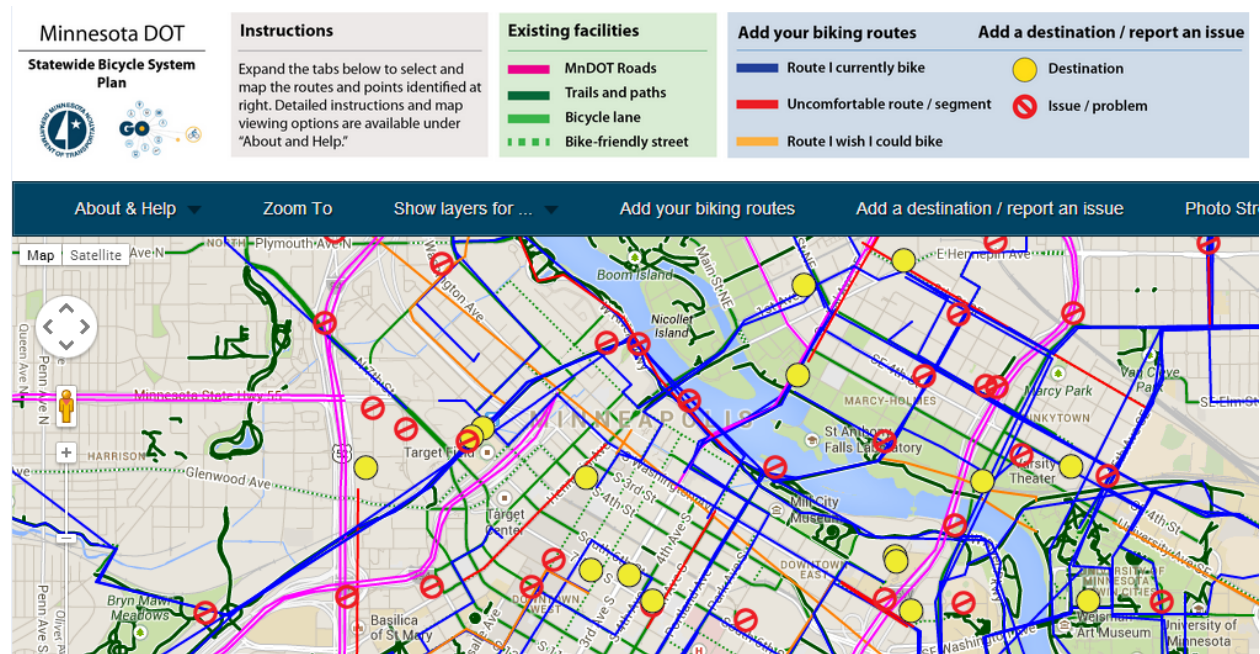


FIGURE 11: MNDOT-HOSTED BICYCLE SYSTEMS WIKIMAPPING PROJECT, “CYCLOPATH”⁷³

⁷¹ Misra et al. 2013.

⁷² <http://cyclopath.org/>

⁷³ <http://wikimapping.com/wikimap/MnDOTBikePlan.html>

A general strategy that has proven successful to collect bike trip data is to deploy a simple smartphone application that allows cyclists to record bicycle trip route, average speed, distance, and simple notes. Cyclists often voluntarily use these apps to help improve local biking facilities. The applications are often coupled with a dedicated web site that allows users to provide additional notes and interact collaboratively with other users and planners.⁷⁴ Some projects do not include a mobile application but instead use a web-based forum.⁷⁵ While a web-based application might not include automated field-data collection, it might attract the efforts of enough contributors to result in a relatively comprehensive system map (Figure 11). Another resource is Google Maps, which has a bicycle route layer and allows users to navigate with the mobile app on a bicycle navigation setting that prefers these routes.⁷⁶

5.4 PARKING MANAGEMENT

Finding available parking spots can be extremely difficult in many cities. Recent research has uncovered serious negative externalities associated with inefficiency in the parking process, such as increased congestion, noise, air pollution, time delays, and safety hazards.⁷⁷ It has been suggested that up to 30% of inner-city traffic congestion is caused by people looking for parking spots.⁷⁸

Some municipalities have experimented with deploying a network of sensors to collect and report data on street-parking availability.⁷⁹ A variety of developers have attempted to address parking by developing apps that facilitate the dissemination of parking availability information. Unfortunately, crowdsourced parking information systems usually suffer low user participation, likely due to a lack of incentive to report vacant spots.⁸⁰ Developers are continuing to look for ways to crowdsource parking availability by developing an incentive scheme that also complies with municipal laws.⁸¹

⁷⁴ Misra et. al 2013.

⁷⁵ Krykewycz et al. 2010.

⁷⁶ MnDOT's Cyclopath (Figure 11) is built on top of the Google Maps bicycle map.

⁷⁷ Brook, Ison, and Quddus 2013.

⁷⁸ Shoup 2011.

⁷⁹ <http://sfpark.org/>

⁸⁰ Hoh et al. 2012.

⁸¹ One service, Monkey Parking, allows users to bid for information on a space being held by the seller. Monkey Parking was forced to cease operations in San Francisco due to laws that
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5.5 ORIGIN-DESTINATION STUDIES

As discussed in Section 2.2, many transportation agencies purchase aggregated travel data from cellular service providers to supplement or replace citizen surveys and journals to obtain origin-destination travel data. Another option is to recruit citizen volunteers to download a dedicated smartphone app to automatically obtain data. Using various embedded sensors on the smartphone could also deduce travel mode and additional factors of interest.⁸²

5.6 ENVIRONMENTAL DATA COLLECTION

The U.S. Environmental Protection Agency (EPA) and state/local governments continue to make National Pollutant Discharge Elimination System (NPDES) requirements more stringent. Agencies need more information on how their system functions (from inlets, ditches, outfalls and stormwater devices). As these stormwater devices and features can be extensive, data collection and inspections are expensive to perform and maintain. A number of municipalities have developed customized internet and smart device-based data collection tools.⁸³ It may be beneficial to expand the functionality of smartphone-based reporting by allowing for input from the public. Other research programs have concentrated on developing systems to crowdsource air quality measurements, a process that can be done passively by volunteers who carry a small pollution-detection device.⁸⁴

5.7 PLANNING AND PROJECT PRIORITIZATION

Several transportation agencies have begun using internet and mobile communications platforms to solicit and facilitate public engagement for transportation planning and project prioritization. Using social media can be more effective if planners impose methods of keeping discussions focused and structured. They can do this by deploying purpose-built platforms managed by the planning team. Introducing opportunity cost for participation—such as a brief registration step—can help to eliminate thoughtless and unhelpful

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ban the private sale or rental of public parking spaces. <http://spectrum.ieee.org/view-from-the-valley/at-work/start-ups/drawing-the-line-between-peertopeer-and-jerk-technology>

⁸² Abdulazim, et al. 2011; Safi et al. 2015.

⁸³ For example, <http://www.esri.com/esri-news/arcnews/summer13articles/idaho-transportation-department-connects-field-crews-with-arcgis-online>

⁸⁴ <http://www.wired.com/2014/11/clarity-wearable/> accessed November 2014.

comments. The registration process may also help prioritize target constituencies. If personal attacks are a potential problem, planners can consider prohibiting anonymous contributions. Planners also have the option of moderating discussions and removing abusive posts.

A few agencies are employing custom-developed transportation planning and prioritization applications.⁸⁵ This method of eliciting public participation has gained enough popularity that companies now offer ready-made platforms and can work with agencies to deploy an online public participation strategy quickly. An example of one such platform is shown in Figure 12, below.

Crowdsourcing in Practice

Open Town Hall

Open Town Hall by Peak Democracy, Inc. is a cloud-based online civic engagement platform. Peak Democracy works with public sector clients to tailor the platform for specific projects or purposes. Such platforms allow governments to maintain control of the public engagement process, an advantage over public participation strategies that leverage existing social networks such as Facebook.



Constituents want
to participate in civil online forums

Government leaders need
online forums that build public trust in government

~ FIND OUT HOW ~

OPEN TOWN HALL provides both

FIGURE 12: OPEN TOWN HALL—A READY-MADE PLATFORM FOR INTERNET-BASED PUBLIC PARTICIPATION

⁸⁵ For example, Brabham, Sanchez, and Bartholomew 2009, constructed a project website to solicit designs for a bus stop.

6 INTEGRATING CROWDSOURCED DATA INTO EXISTING AGENCY PRACTICES

The preceding chapters established that transportation agencies can use crowdsourcing in four basic ways:

- Third-party Aggregated Crowdsourced Data
- Social Media for Public Engagement
- The Internet as a Sensor
- Dedicated Platforms for Transportation System Management

This chapter will discuss how agencies can integrate crowdsourced data into existing practices. Figure 13, below, provides one model of data flows within transportation agencies that can be used to structure the discussion.

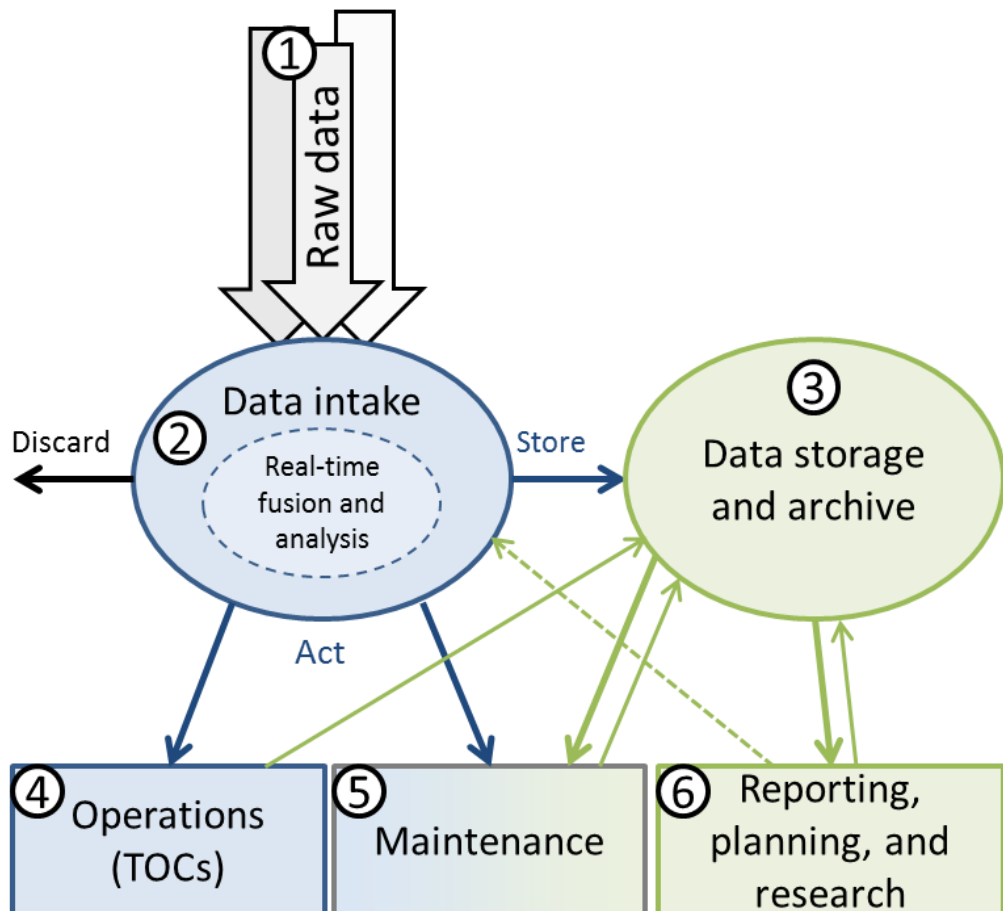


FIGURE 13: DATA FLOWS WITHIN A TRANSPORTATION AGENCY

6.1 OBTAINING RAW DATA

Component 1 of Figure 13 represents the entirety of data that a transportation agency monitors or collects. These raw data streams include any crowdsourced data, as well as traditional data such as sensor readings, inspection reports, construction documents, etc. Data used by transportation agencies can be obtained in a practically unlimited number of formats. Some crowdsourced data sets are pre-aggregated and structured, such as the traffic speed and travel time data provided to MDOT by HERE. Crowdsourced data also can be largely unstructured, such as posts to social media sites like Twitter and Facebook. Additionally, data may be structured, but in such a way that is not convenient for agency use.⁸⁶ The nature and structure of incoming data impacts how the agency processes the data internally.

6.2 DATA INTAKE PROCESS

At the point when raw data is obtained by an agency, the agency necessarily takes some immediate action in response to receiving the data. Component 2 of Figure 13 is represented abstractly as a singular data-intake process through which all agency data must pass. However, in real-world systems, raw data is obtained in a range of formats and structures that require a range of overlapping unique data-intake processes. Data can be structured, semi-structured, or unstructured, and might not even be digital.⁸⁷

Upon receipt of raw data, agencies can respond in four fundamental ways:

- Ignore and discard data
- Act on data in real-time
- Store data
- Real-time data fusion and analysis (followed by one or more previous options)

⁸⁶ An example such ‘semi-structured’ data is crowdsourced incident information reported via the Waze app. While there is a data structure to Waze incident reports, agencies must actively monitor the Waze cite and manually respond in order to use the information in some way (unless the agency has a partnership with Waze that allows access to backend data).

⁸⁷ Examples of non-digital data include inspection notes, printed reports, construction drawings, etc. Data also can arrive verbally (e.g., a notice provided by law enforcement officials).

Agencies may choose to ignore and discard raw data that are not particularly beneficial. For example, many transportation agencies receive a constant stream of traffic speed information. If the data reveals no problems that require attention by operations or maintenance divisions, then the data may be discarded without being acted upon.⁸⁸

Some data has value without being actionable in real-time. Examples include inspection records, field-notes, construction drawings, etc. Such data is often stored and archived for later use. A record of actions taken by TOCs and any measurable results can also be stored for later analysis to evaluate TOC efficacy.

REAL-TIME DATA FUSION AND ANALYSIS

Many transportation agencies are investigating ways to improve performance and tracking by using real-time data fusion and analysis. For example, one can imagine a data intake process that simultaneously monitors individual data sources (e.g., traffic speed sensor data, environmental sensor station data, National Weather Service forecasts, etc.) and identifies potential congestion events before they occur by analyzing the relationships between these data and comparing real-time conditions to historical congestion events. Such an analytical engine could allow operations and maintenance crews to deploy mitigation tactics significantly earlier than if individual data streams are monitored without additional analysis. Such real-time data fusion and analysis essentially creates new data, in a new format, which the agency was unable to obtain directly from raw data feeds.⁸⁹

The new data generated by real-time data fusion and analysis during the data intake process would then be subject to the same possible fates as previously discussed. If the new data have no value, then they might be discarded immediately. If the data have value in real-time, then they probably will be acted upon by TOCs or maintenance crews or both. If the data can provide value later, then they likely will be stored and archived.

⁸⁸ Alternately, DOTs may archive this data for reporting, planning, research, and related uses. MDOT does not need to archive live traffic data because it receives historical traffic speed data reports from HERE, separately from real-time data.

⁸⁹ Beggs 2014.

6.3 DATA STORAGE AND ARCHIVING

For the sake of simplicity, Figure 13 represents component 3 as a single storage and archive process. As with the data intake process, the reality is much more complicated. Transportation agencies often store and archive numerous types of data in numerous formats. Some archival data follow legacy formats, and some might not even be digital.⁹⁰

Additionally, Figure 13 oversimplifies the relationship between storage and archival by including any data that is not used in real-time. This is a useful abstraction when focusing on the potential uses of crowdsourcing. However, in practice, data storage and archiving are distinct concepts and require distinct approaches.⁹¹ Put simply, *data storage* refers to data that is being actively used, or can be manipulated in the near or medium term. *Data archiving* describes sending data to a ‘final resting place,’ but in such a format that it can be referenced and brought into active use when necessary.

MDOT’s data architecture is likely to be updated in the near future as a result of ongoing efforts like the Data Use Analysis and Processing (DUAP) system, a Transportation Asset Management System (TAMS) proposal,⁹² and a statewide Data Modernization, Assurance, and Governance (DMAG) project. These various efforts are being implemented to allow MDOT and other State of Michigan agencies to make better and more efficient use of all types of data, including crowdsourced data.

As data storage and archiving schemes are developed, MDOT and the State of Michigan should explore adaptive and scalable solutions offered by cloud service providers as a replacement for, or compliment to, internally-hosted custom-developed or commercial-off-the-shelf (COTS) platforms. Cloud-based asset management platforms are now mature, customizable, price-competitive, and a good way to prepare for uncertainties in the future developments of asset management programs.

⁹⁰ E.g., physical (paper) files.

⁹¹ A more complete discussion of data use would require the additional concept of data backup in addition to storage and archival.

⁹² Formerly known as the Enterprise Asset Management System (EAMS) Solution. This project was released for bids in 2014. It is not known to have been awarded as of Nov 11, 2014.

6.4 TRANSPORTATION OPERATIONS CENTERS

MDOT and local TOCs currently utilize various types of data to improve the performance of the transportation system. A summary of data types currently monitored and collected by Michigan TOCs is given in Table 3. TOCs value data that can be acted on in real time. Currently (with the exception of adjusting travel time signs) the task of monitoring pertinent data and acting on it remains largely manual. TOCs receive important information via email, radio communications, phone calls, or even personal conversations.⁹³ Actions could include adjusting DMS messages, deploying police or agency personnel, and disseminating information (e.g., through email listservs, MiDrive, Twitter, Waze, etc.). Local TOCs also might respond to traffic conditions by adjusting signal timing. In the near/mid-term, human operators will likely continue to be a bridge between any incoming data and the subsequent response. As such, the format of any data is not particularly important, as long as it reaches the right people with minimal delay. Additionally, while TOCs often report that all information could be valuable, this labor-intensive process of interpreting data and deciding how to act on it means that TOCs could be susceptible to information overload. Future transportation management systems (TMS) and TOCs may become much more automated. If transportation agencies wish to incorporate crowdsourced data into an automated TMS, the TMS architecture will have to accommodate whatever data formats are to be used.

Figure 13 shows that real time data flows into TOCs, but also shows a data flow from TOCs to a data storage and archive process. This data flow represents any information retained by agency as a result of TOC operations. Such data is most often used for reporting and activity tracking, but can also be used to evaluate and improve TOC operations. For example, TOCs might record congestion locations and agency responses to evaluate the efficacy of different response strategies.

⁹³ Personal information sharing is particularly evident at RDMC TOC and SEMTOC, as both TOCs have strategically created shared space for traffic operators and police dispatch.

TABLE 3: MICHIGAN TOC RAW DATA SOURCES AND POTENTIAL RESPONSES

Raw Data Source	Use and Potential Response
Microwave Vehicle Detection Stations (MVDS) and MiDrive	MDOT's MVDS provide average vehicle speed over discrete time bins. MVDS data are combined with HERE sensor and probe vehicle data to populate MiDrive and provide estimated travel times as shown on DMS. Areas of congestion might prompt traffic operators to deploy freeway courtesy patrol (FCP), emergency maintenance crews, or MSP. TOCs might also post incident information to DMS, MiDrive, and Twitter. Dedicated travel-time signs are updated automatically by the TMS without manual TOC action.
Closed Circuit Television (CCTV) cameras	MDOT and local TOCs utilize CCTV cameras to monitor and verify traffic and weather conditions. Observed problems might prompt traffic operators to deploy FCP, emergency maintenance crews, or MSP. ⁹⁴ TOCs might also post incident information to DMS, MiDrive, and Twitter. Local TOCs might adjust signal timing. MCRD TOC posts incident data to Waze, which then pushes data to Google Maps Traffic. RCOC has a wide array of CCTV cameras, but many are used only to control signal timing and are not transmitted to the RCOC TOC.
Police Dispatch	MSP or local police might report pertinent issues (e.g., crashes and associated road-closures) to TOCs. Traffic operators might post incident information to DMS, MiDrive, and Twitter. MCRD TOC posts incident data to Waze, which is then pushed to Google Maps Traffic.
Agency Reports	Field personnel from MDOT or local agencies often report pertinent issues to TOCs (e.g., construction and associated lane closures). Traffic operators might post incident information to DMS, MiDrive, and Twitter. MCRD TOC posts incident data to Waze, which then pushes data to Google Maps Traffic.
Waze	The MCDR TOC monitors Waze for crowdsourced traffic speed and incident reports. Traffic operators generally verify the incident by observing CCTV cameras or deploying field personnel before further action is taken in response to crowdsourced data.
Google Maps Traffic	MDOT regional and local TOCS monitor Google Maps Traffic layer to stay aware of congestion issues—particularly on surface streets or regions where MiDrive coverage is less accurate.

⁹⁴ Or, in the case of the MDOT Bluewater Bridge TOC, traffic operators monitor CCTV feeds and respond to emerging issues by coordinating with U.S. Customs and Border Patrol, and possibly the Canadian Border Services Agency, to move traffic efficiently across the bridge.

6.5 MAINTENANCE

Deploying maintenance crews requires the use of both real-time and stored data, as demonstrated in the associated component 5 of Figure 13.

Maintenance garages, like TOCs, use live data feeds (e.g., traffic cameras, environmental sensor stations, national weather service feeds, field reports, etc.) to respond to traffic and road conditions in real-time. Alternately, many routine maintenance projects are scheduled in advance.



FIGURE 14: MAINTENANCE CREWS PERFORM BOTH REACTIVE AND SCHEDULED MAINTENANCE

When real-time information is used, the format of the data is not especially important (similar to TOC perspectives). Most critically, pertinent data must reach the right people with minimal delay. If crowdsourced data is used in association with planned maintenance services, then the data must be integrated into broader databases or other decision support systems used by maintenance

garages to plan, schedule, and deploy crews. Many maintenance operations use a computer-aided dispatch (CAD) system to schedule and deploy maintenance crews. Crowdsourced data would likely have to be integrated or otherwise merged with these existing CAD programs to impact scheduled maintenance activities.

MDOTs ongoing Transportation Asset Management System (TAMS) project will likely determine the future of transportation asset management planning and maintenance.⁹⁵ As of November 2014, the TAMS project is in bid stage and project parameters have not been finalized. MDOT should work with the chosen contractor to implement a TAMS architecture that is customizable and scalable so that novel data sources—such as crowdsourced data—can be integrated into MDOTs asset management and maintenance decisions.⁹⁶

⁹⁵ MDOT 2013b.

⁹⁶ An additional MDOT project that might impact such processes is the Weather Responsive Traveler Information System (Wx-TINFO) Implementation. http://www.michigan.gov/documents/mdot/09-22-2014_Wx-TINFO_Concept_of_Operations_471193_7.pdf, last accessed November 2014.

6.6 REPORTING, PLANNING, AND RESEARCH

Component 6 of Figure 13 includes any reporting, planning, and research activities conducted by any division of the transportation agency as well as external organizations that have access to data for research purposes. These processes generally use stored and archived data, as opposed to real-time information. Such historical data can be used to improve the data intake process such that TOCs have access to better real-time data, and more useful data is captured for storage and archiving, closing the data-analysis loop. The reporting, planning, and research efforts of a transportation agency are highly dependent on having a data storage and archiving system (component 3) that is adaptive and scalable.



7 SUMMARY AND CONCLUSIONS

Crowdsourcing involves leveraging the combined intelligence, knowledge, or experience of a group of people to answer a question, solve a problem, or manage a process. Crowdsourcing has the potential to address a growing range of problems due to the broad adoption of internet-connected devices, especially smartphones. Leveraging this network of connected devices for transportation system management is an important opportunity.

THIRD-PARTY AGGREGATED CROWDSOURCED DATA

Many transportation agencies already use crowdsourced data through contracted commercial providers. Commercial providers offer clearly defined products and services, as well as customer support and professional expertise. Such arrangements allow agencies access to proprietary data that would otherwise be difficult to obtain, and allow them to avoid tedious data cleaning and management tasks. Agencies can avoid dealing with sensitive personally identifiable information by receiving only aggregated data from providers. Transportation agencies have already established practices of purchasing aggregated third-party data for live and historical traffic data, as well as origin-destination studies. Purchasing additional types of third-party data is a future possibility.

SOCIAL MEDIA FOR PUBLIC ENGAGEMENT

Americans spend more time using social networks than any other online activity. The communication potential of these sites represents extensive possibilities for improving the planning, management, and operations of the transportation system. Social media outlets such as Twitter can be extremely useful for communicating system status during special events and disruptions. Agencies can simultaneously disseminate information, gather additional information from system users, and take advantage of instantaneous unmediated information sharing on the platform.

The raw number of people a transportation agency could potentially reach through existing social media platforms is substantial. Additionally, the increasing popularity of platforms such as Facebook allow for broad demographic representation. Some planners have successfully experimented with engaging constituencies via these popular platforms to supplement and support traditional public participation. Using social media might be more effective if planners impose methods of keeping discussions focused and

structured. This can be done by deploying purpose-built platforms managed by the planning team. This method of eliciting public participation has gained enough popularity that companies now offer ready-made platforms and can work with agencies to quickly deploy an online public participation strategy.

THE INTERNET AS A SENSOR

The continued increase of connected people and devices can provide agencies access to completely new types of data. Recent research in transportation demand modeling has investigated the concept of using the internet itself as a virtual sensor capable of providing valuable, actionable data. Internet-as-a-sensor applications are just beginning to be adopted in select industries. These applications utilize developing approaches to data science such as data-mining and machine learning. Early-adopting agencies have the opportunity to utilize internet-as-a-sensor methods to develop innovative solutions to transportation systems management.

Traditional public participation methods (e.g., community meetings) often result in low community involvement and over representation of special interests. Many of these people, while not easily reachable by planning agencies, are active on social media, and some of them even discuss transportation-related issues in these forums. Extracting public sentiment information from open internet resources is an extensively studied topic. As these methods continue to develop, transportation planners should consider using such techniques to supplement traditional methods of acquiring public participation data. Many of these platforms can also be used as a tool for information dissemination and as a source of data.

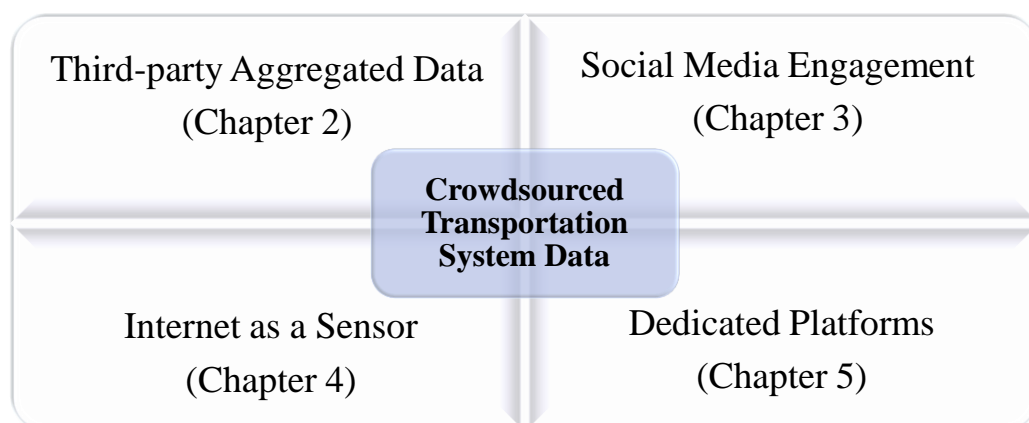
Drivers have already come to rely on free traffic data access over the internet and mobile apps. Recent work has investigated the possibility of using such data to supplement or supplant traditional traffic sensor networks. Using the internet as a virtual sensor to measure network travel time, researchers have shown that open traffic data can be used to obtain network traffic speed estimations that are equal or better to traditional sensor networks.

Some researchers have investigated the potential to use the internet as a sensor to predict the impact that special events, such as festivals and sporting events, have on the transportation system. Such research has revealed that irregular spikes in traffic demand can be predicted by scanning live-streaming data from social media and other internet sources.

DEDICATED PLATFORMS FOR TRANSPORTATION SYSTEM MANAGEMENT

Crowdsourced data collection using custom-built smartphone applications is rapidly gaining momentum within multiple industries. The potential applications of crowdsourcing will continue to diversify in the future as technology and communications continues to improve. Potential uses for dedicated transportation-focused crowdsourcing applications include:

- Automated Vehicle Location for Public Transit
- Pavement Condition Data Collection
- Bicycle Travel and Infrastructure Data
- Parking Management
- Origin-Destination Studies
- Environmental Data Collection
- Planning and Project Prioritization



INTEGRATING CROWDSOURCED DATA INTO EXISTING AGENCY PRACTICES

Agencies can acquire raw data in a wide variety of formats. After intake, raw data are handled by the agency in one of four ways:

- Ignore and discard data
- Act on data in real-time
- Store data
- Real-time data fusion and analysis (followed by one or more previous options)

Agencies can develop various tools for real-time data fusion and analysis to improve operations, maintenance, planning, and research processes. Such techniques create new data that was not otherwise available to the agency in raw form. Upon real-time creation of this new data, the intake process cycles back and a decision must then be made to ignore and discard the data, act on it in real-time, or store it for later use.

Any data that is retained is subject to data storage and archival processes. These data are used for reporting, scheduling, planning, and research. The data storage and archival process should be adaptable and scalable to facilitate access and use for stored data, including data in non-traditional formats such as crowdsourced data.⁹⁷

Reactive traffic management strategies are usually implemented by traffic operations centers (TOCs) and maintenance crews. TOCs value data that are actionable in real-time. Most TOCs utilize proven and well-established methods of collecting real-time data for their purposes. For example, MDOT's TOCs are highly dependent on police dispatch reports, highway monitoring cameras, and average traffic speeds provided by contract.⁹⁸ TOCs have a range of options in which to respond to traffic condition. These include adjusting roadside dynamic message signs, alerting police or emergency services, and alerting agency maintenance crews. Most actions taken by TOCs will have a human in the loop in the near- to mid-term. As such, if crowdsourced traffic data are integrated into TOC procedures, the particular format of the raw data is not particularly important; more crucial is that traffic operators receive actionable information with minimal delay. Future transportation management systems may be more highly automated, and will take action without a human in the loop. Such systems will have to be designed to include appropriate data formats if agencies wish to include crowdsourced data in automated TMS operations.

Maintenance operations are generally more sensitive to the format of incoming data than TOCs. While maintenance crews often respond to traffic information in real-time, most of their operations are scheduled in advance, even in the short-term, through computer-aided dispatch (CAD) software. For maintenance crews to most effectively utilize any kind of crowdsourced data,

⁹⁷ The Michigan Data Modernization and Governance (DMAG) and MDOT's Transportation Asset Management System (TAMS) are currently under development to such purposes.

⁹⁸ MDOT's traffic speed data is provided by HERE, which combines MDOT sensor data which a proprietary network of sensors and probe vehicles.

it would likely have to be somehow integrated into an agency's existing CAD program.

Any data that is retained is affected by an agency's storage and archival process. MDOT's data storage and archive architecture is likely to be updated in the near future as a result of ongoing projects, such as the Data Use and Processing (DUAP) project, a Transportation Asset Management System (TAMS) proposal,⁹⁹ and a statewide Data Modernization, Assurance, and Governance (DMAG) project. These various efforts are being implemented to allow MDOT and other State of Michigan agencies to make better and more efficient use of all types of data, including crowdsourced data. As data storage and archiving schemes are developed, MDOT and the State of Michigan should explore adaptive and scalable solutions offered by cloud service providers in as a replacement for, or compliment to, custom-developed or commercial-off-the-shelf (COTS) platforms hosted internally. Cloud-based asset management platforms are now mature, customizable, price-competitive, and a good way to prepare for uncertainties in the future developments of asset management programs. The customizability and ongoing support features in cloud-based data storage also can facilitate best use of existing data in any reporting, planning, and research processes.

⁹⁹ Formerly known as the Enterprise Asset Management System (EAMS) Solution. This project was released for bids in 2014. It is not known to have been awarded as of Nov 11, 2014.

REFERENCES

- Abdulazim, Tamer; Hossam Abdelgawad; Khandker Nurul Habib; and Bahar Abdulhai. "Using Smartphones and Sensor Technology to Automate the Collection of Travel Data." University of Toronto. TRB 2011 Compendium of Papers. 2011.
- Al-Deek, Haitham; Srinavasa Ravi Chanra Chilakamarri Venkata; Jason Flick; and Asad Khattak. "Dynamic Message Sign Deployment and Diversion Behavior of Travelers on Central Florida Toll Roads." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2129, Transportation Research Board of the National Academies, Washington, D.C., pp. 24-34, 2009.
- Beggs, Ronnie. "Streaming Big Data Management as a Platform for Real-time Traffic Flow Analysis and Dynamic Congestion Management." SQLstream. ITS World Congress 2014.
- Brabham, Daren C.; Thomas W. Sanchez; and Kieth Bartholomew. "Crowdsourcing Public Participation in Transit Planning: Preliminary Results from the Next Stop Design Case." University of Utah. TRB 2010 Annual Meeting Compendium of Papers. August 1, 2009.
- Brooke, Sarah; Stephen Ison; and Mohammed Quddus. "On-Street Parking Search: a review and future research direction." TRB 2014 Compendium of Papers. Submitted November 2013.
- Cambridge Systematics, Inc. "Travel Time Data Collection." White Paper. Florida Department of Transportation, District IV. January 31, 2012.
- Chan, Raymond and Joseph L. Schofer. "The Role of Social Media in Communicating Transit Disruptions." Northwestern University. Transportation Research Board 2014 Annual Meeting Compendium of Papers. Submitted July 2013.
- Chen, Xiao; Fang He; Siriphong Lawphongpanich; and Yafeng Yin. "Optimal Travel Time Displays for Dynamic Message Signs." University of Florida. TRB 2012 Annual Compendium of Papers. Submitted August 2011.
- Dennis, Eric Paul; Josh Cregger; and Qiang Hong. *ITS Data Ethics in the Public Sector*. Center for Automotive Research and Michigan Department of Transportation. July 2014.
- Dennis, Eric Paul; Qiang Hong; Richard Wallace; William Tansil; and Matt Smith. *Pavement Condition Monitoring with Connected Vehicle Data*. Center for Automotive Research and Michigan Department of Transportation. January 22, 2014.

- Evans-Cowley, Jennifer and Greg Griffin. "Micro-participation: Community Engagement in Transportation Planning with Social Media." TRB 2012 Annual Meeting Compendium of Papers. Submitted November 2011.
- Evans-Cowley, Jennifer. "Evaluation of the Social Networking and Planning Project." Texas Citizens Fund. SNAPPatx. January 29, 2011.
- Galton, Francis. "Vox Populi." *Nature*. No. 1949, Vol. 75. Pp. 450. March 7, 1907.
- Glotzbach, Gene. "The Waze Connection." *Sunguide Disseminator*. Florida Department of Transportation. August 2014.
- Hadi, Mohammed; Louo Shen; Chengjun Zhan; Yan Xiao; Steven Corbin; and Dong Chen. "Operational Data for Evaluating Benefits and Costs of Advanced Traffic Management Components." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2086, Transportation Research Board of the National Academies, Washington, D.C., pp. 48-55, 2008.
- Hanhani, Ali; Masoud Hamedi; Robin Fish; and Azedeh Nouruzi. "Evaluation of Dynamic Message Signs and their Potential Impact on Traffic Flow." University of Maryland. April 2013.
- Hernandez, Jessica; Yi-Chang Chui; and Hua Yang. "Statistical Assessment of the Impact of Dynamic Message Signs on Highway Traffic Redistribution." TRB 2010 Annual Compendium of Papers. 2010.
- Hoh, Baik; Tingxin Yan; Deepak Ganesan; Kenneth Tracton; Toch Iwuchukwu; and Juong-Sik Lee. "TruCentive: A Game-theoretic Incentive Platform for Trustworthy Mobile Crowdsourcing Parking Services." 15th International IEEE Conference on Intelligent Transportation Systems. 2012.
- Kitamura, Ryuichi and Shoichiro Nakayama. "Can Travel Time Information Really Influence Network Flow? Implications of the Minority Game." Kyoto University. March 2007.
- Krykewycz, Gregory R.; Christopher Pollard; Nicholas Canzoneri; and Elizabeth He. "A Web-based Crowdsourcing Approach to Improve Area-wide Bikeability Scoring." Delaware Valley Regional Planning Commission (DVRPC). TRB 2011 Annual Compendium of Papers. Submitted October 2010.
- Kurkcü, Abdulla; Ender Faruk Morgul; Kaan Ozbay. "Extended Implementation Methodology for Virtual Sensors: Web-based Real Time Transportation Data Collection and Analysis for Incident Management." *2015 Annual Meeting of the Transportation Research Board*. Washington, D.C. Compendium of Papers. 2015.

- Lee, J. F. Jennifer and Jeffrey Williams. “A New Way to Utilize Remote Sensing Data – Automated Road Travel Survey.” TRB 2014 Compendium of Papers. Submitted Nov 2013.
- Liou, Ren-Huang; Yi-Bing Lin; Yu-Long Chang; Hui-Nien Hung; Nan-Fu Peng; Ming-Feng Chang. “Deriving the Vehicle Speeds from a Mobile Telecommunications Network.” *IEEE Transactions on Intelligent Transportation Systems*. Vol. 14, No. 3, September 2013.
- Madrigal, Alexis C. “How Google Builds Its Maps—and What It Means for the Future of Everything.” *The Atlantic* Online. September 6, 2012.
- MDOT (Michigan Department of Transportation) and Center for Automotive Research (CAR). MDOT ITS Investment Plan. September 2013.
- MDOT (Michigan Department of Transportation). Enterprise Asset Management System Concept of Operations (ConOps) Briefing Report. (Final Report) March 12, 2013 (2013b).
- Misra, Aditi; Aaron Gooze; Kari Watkins; Mariam Asad; Christopher A. Le Dantec. “Crowdsourcing and Its Application to Transportation Data Collection and Management.” Georgia Institute of Technology. TRB 2014 Annual Compendium of Papers. Submitted November 2013.
- Mitchell, Amy and Emily Guskin. “Twitter News Consumers: Young, Mobile and Educated.” Pew Research Journalism Project. November 4, 2013.
- Morgul, Ender Faruk; Hong Yang; Abdullah Kurkcü; Kaan Ozbay; Bekir Bartın; Camille Kamga; Richard Salloum. “Virtual Sensors: A Web-based Real-time Data Collection Methodology for Transportation Operation Performance Analysis.” NYU-Poly Center for Urban Science + Progress (CUSP). TRB 2014 Annual Compendium of Papers. Submitted November 2013.
- Murthy, Gummada; Jian Lu; and Lakshminarayan Rajaram. “Development and Application of DMS Operations Evaluation Models (DOEM).” University of South Florida. TRB 2012 Annual Compendium of Papers. Updated for publication March 2012.
- Nagle, Andrew S. and Vikash V. Gayah. “The Accuracy of Network-wide Traffic State Estimation Using Mobile Probe Data.” The Pennsylvania State University. TRB 2014 Annual Compendium of Papers. Submitted November 2013.
- Ni, Ming; Qing He; and Jing Gao. “Using Social Media to Predict Traffic Flow under Special Event Conditions.” University of Buffalo, SUNY. Transportation Research Board 2014 Annual Meeting Compendium of Papers. Submitted November 2013.

- Pang, Bo; and Lillian Lee. "Opinion Mining and Sentiment Analysis." *Foundations and Trends in Information Retrieval*. Vol. 2, No 1-2. pp. 1-135. 2008.
- Pereira, Franciso Camara; Filipe Rodrigues; and Moshe Ben-Akiva. "Internet as a sensor: a case study with special events." Singapore-MIT Alliance for Research and Technology (SMART). August 2011.
- Russell, Matthew A. "Mining the Social Web." (Second Edition.) O'Reilly Media. 2013.
- Safi, Hamid; Behrang Assemi; Mahmoud Mesbah; Lius Ferreira; Mark Hickman. "Design and Implementation of a Smartphone-based System for Personal Travel Survey: Case Study From New Zealand." *2015 Annual Meeting of the Transportation Research Board*. Washington, D.C. Compendium of Papers. 2015.
- Shoup, Donald. "Cruising for Parking." *Access*, No. 30, Spring 2007.
- Steinfeld, Aaron; John Zimmerman; Anthony Tomasic; Daisy Yoo; and Rafae Dar Aziz. "Mobile Transit Ride Information Via Universal Design and Crowdsourcing." Carnegie Mellon University. TRB 2011 Annual Compendium of Papers. Submitted 2010.
- Thiagarajan, Arvind; Lenin Ravindranath; Katrina LaCurts; Samuel Madden; Hari Balakrishnan; Sivan Toledo; and Jakob Eriksson. "VTrack: Accurate, Energy-Aware Road Traffic Delay Estimation Using Mobile Phones." *SenSys '09 (Conference)*. Berkeley, CA. November 4-6. 2009.
- Vasudevan, Meenakshy; Karl E. Wunderlich; Carolina Burnier; and Richard Glassco. "Mobility and Commute Disutility Effects of 511 Deployment in Salt Lake City, Utah." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2086, Transportation Research Board of the National Academies, Washington. D.C., pp. 64-71, 2008.
- Wang, Tingting; Cynthia Chen; and Jingtao Ma. "Mobile Phone Data as an Alternative Data Source for Travel Behavior Studies." TRB 2014 Annual Compendium of Papers. Submitted July 2013.
- Zhang, Yucheng; Ping Yi; Kevin L. Kreider; Chun Shao; and Timothy S. Norfolk. "Modelling Network Impact in the Surrounding Area of Activity Center Due to Special Events." University of Akron, Ohio. TRB 2010 Annual Compendium of Papers. Submitted 2009.

SUPPLEMENTARY BIBLIOGRAPHY

- Barbeau, Sean J. and Tatu Saloranta. "Performance Evaluation of Transit Data Formats on a Mobile Device." TRB 2014 Compendium of Papers. Submitted November 2013.

- Bessler, Sandford and Thomas Paulin. "Literature Study on the State of the Art in Probe Data Systems in Europe." FTW Telecommunications Research Center Vienna. September 10, 2013.
- Eriksson, Jakob; Lewis Girod; Bret Hull; Ryan Newton; Samuel Madden; and Hari Balakrishnan. "The Pothole Patrol: Using a Mobile Sensor Network for Road Surface Monitoring." *MobiSys '08*. (Conference) Breckenridge, Colorado. June 17-20, 2008.
- Gal-Tzur, Ayelet; Susan Grant-Muller; Einat Minkov; and Silvio Nocera. "The Impact of Social Media Usage on Transport Policy: Issues, Challenges and Recommendations." *Procedia – Social and Behavioral Sciences* 111 (2014) pp. 937-946. Elsevier Ltd. 2013.
- Google. "The bright side of sitting in traffic: Crowdsourcing road congestion data." *Google Official Blog*. <http://googleblog.blogspot.com/2009/08/bright-side-of-sitting-in-traffic.html> August 25, 2009.
- Grant-Muller, Susan; Ayelet Gal-Tzur; Einat Minkov; Silvio Nocera; Tsvi Kuflik; and Itay Shoor. "The Efficacy of Mining Social Media Data for Transport Policy and Practice." TRB 2014 Compendium of Papers. 2014.
- Islam, Shahidul; William G. Buttlar; Roberto G. Aldunate; and William R. Varvik. "Measurement of Pavement Roughness Using an Android-Based Smartphone Application." TRB 2013 Compendium of Papers. 2013.
- Jiayi, Liu. "Baidu develops 'smart bike' and its operating system." *ZDNet*. November 26, 2014. <http://www.zdnet.com/baidu-develops-smart-bike-and-its-operating-system-7000036166/>
- Kanhere, Salil S. "Participatory Sensing: Crowdsourcing Data from Mobile SmartPhones in Urban Spaces." University of South Wales. IEEE Int. Conference on Mobile Data Management. 2011.
- Lei, Hao; Tao Xing; Jeffrey D. Taylor; and Xuesong Zhou. "Monitoring Travel Time Reliability from the Cloud: Cloud Computing Based Architecture for Advanced Traffic Information Dissemination." University of Utah. TRB 2012 Compendium of Papers. Submitted 2011.
- Rosado, Wade. "Data Detour: Analytics will Move Transportation Forward." *Wired* online. <http://www.wired.com/2014/07/data-detour-analytics-will-move-transportation-forward/> accessed November 2014. July 10, 2014.
- Transportation Research Board (TRB) of the National Academies. "Uses of Social Media in Public Transportation." Transit Cooperative Research Program (TCRP) Synthesis 99. 2012.

APPENDIX A: TRANSPORTATION-RELATED CROWDSOURCING PLATFORMS

Name of App, Company, or Service	Features	Notes
Apple Maps	Provides mapping services including turn-by-turn navigation for driving and walking.	Proprietary maps with support from TomTom. Proprietary traffic data (iPhones used as probes) also use TomTom/Inrix for traffic ¹ . Available only on IOS and OS X operating systems.
Beat the Traffic	Navigation app for commuting. Allows users to save routes and provides real-time traffic information on each route with estimated best route. Does not provide turn-by-turn navigation.	App is free with advertisements. Uses Google maps API. Interesting feature: notifies about special events and predicted impact.
Cellint	Commercial Traffic Data Provider uses combination of probe vehicles and other sources.	Extensive product offerings. Government clients in Israel and U.S.
Cyclopath	MnDOT bicycle infrastructure wikimapping project	Builds on Google Maps Bicycle layer. Users contribute bike routes, suggestions, issues.
FixMyStreet	Issue Reporting (Asset Management, Maintenance.) U.K. Program.	Report, view, or discuss local problems like potholes, graffiti, fly tipping, broken paving slabs, or street lighting. Data sent to appropriate agency. Some councils adopting platform as formal reporting mechanism.
FixMyTransport	Issue Reporting (Asset Management, Maintenance) U.K. Program.	Notify operators of problems with rail, bus, tube, and ferry services (e.g., broken ticket machines, buses off schedule, or silly rules). Data sent to appropriate agency.
Google Maps	Web and mobile application provides live traffic conditions. Mobile application provides GPS navigation with live re-routing based on traffic conditions. Also provides navigation for public transit, walking, and biking options. Turn-by-turn voice	This free navigation app is the most popular mobile app in the world. In terms of quantity, Google Maps is the most popular smartphone app in the world; not just the most popular navigation app, but the most popular app overall. ² This is generally considered the standard measure of navigation app capability. Many location-based apps use the

¹ <http://gizmodo.com/5917658/tomtom-confirms-its-involvement-with-ios-6-maps> accessed July 2014.

² <http://www.businessinsider.com/google-smartphone-app-popularity-2013-9#infographic> accessed April 2014.

	directions. Integrated search feature.	Google Map's API to supply a basemap for additional services.
Inrix	Commercial traffic information service uses data fusion from proprietary fleet with public and municipal sources to offer a variety of products.	Provides built-in navigation platform for many vehicle manufacturers.
Lyft	Mobile ridesharing service operates similar to a taxi service with privately-owned vehicles	Legal issues remain unresolved in many areas.
Mobile Millenium	Created a probe vehicle network of volunteers' smartphones for live traffic measurement and information.	PPP between UC Berkeley, Nokia, NAVTEQ and CalTrans. Project is complete and was not pursued.
Moovit	Public Transit Navigation and Information App for smartphones	Available in many cities worldwide and in the U.S. including Ann Arbor.
HERE	Maps and traffic data provider.	Owned by Nokia. Provides services to multiple public and private sector clients including embedded vehicle navigation systems. Notable for availability of 3D maps.
OpenStreetMap	Open source road network basemap uses crowdsourcing for map corrections.	Unlike other mapping projects, OpenStreetMap does not charge for use by commercial entities. Notable users include Foursquare and MapQuest.
Roadify	Provides GTFS transit data plus a layer of crowdsourced commentary about transit routes and conditions.	Combines AVL feeds from transit agencies with tweets and user information to provide information regarding public transit system use. Free app.
SeeClickFix	Web based reporting for civil government issues.	Site reports issues to appropriate agency. Many city governments actively monitor site.
SFBetterStreets.org	Issue Reporting, planning and improvement suggestions	The website solicits ideas for street improvements, provides accessible descriptions of necessary permit processes, and suggests strategies for building community support.
Strava	Bicycle-focused fitness app.	Aggregated bicyclist data is available to planners.
Street Bump	Volunteers run app while driving and automatically record location of potholes.	Project of City of Boston and ConnectedBits . Records bump "events" (potholes) to assist in pavement maintenance. Currently iOS only.
Sygie GPS Navigation and Maps	Basic stored-map GPS navigation with optional traffic. Reports data back to Inrix.	Uses TomTom/Inrix for map and traffic info.
Telenav	Provides navigation services for	Free smartphone navigation app, "Scout,"

	several platforms using crowdsourced and other data.	contributes probe-vehicle data for use in live traffic data.
Trafficast	Offers a range of traffic data products for public and private clients.	Traffic data derived from multiple open-source and proprietary sources.
Uber	Mobile ridesharing service operates similar to a taxi service with privately-owned vehicles	Legal issues remain unresolved in many areas.
Ushahidi	Provides various crowdmapping products as third-party data provider.	Originally developed in Kenya for mapping crisis situations, but has since been used around the world for various purposes ranging from organizing snow cleaning response to environmental monitoring.
Waze	Smartphone navigation application uses crowdsourcing for traffic speed, incident reporting, and map updates.	Now partnering with transportation agencies for data sharing and integration.
Yip Yap	Location-based anonymous message board.	May be useful to target geographic areas for engagement or data-mining.

APPENDIX B: TRANSPORTATION OPERATIONS CENTER INTERVIEW NOTES

CAR conducted interviews with representatives from the following transportation operations centers (TOCs) to assess how TOCs can best use crowdsourced transportation data:

- MDOT Michigan State Transportation Operations Center (STOC), Lansing.
- Macomb County Department of Roads (MCDR) TOC.
- MDOT West Michigan TOC (WMTOC), Grand Rapids.
- MDOT Southeast Michigan TOC (SEMTOC), Detroit.
- Road Commission for Oakland County (RCOC) TOC.
- Bluewater Bridge TOC (BWBTOC), Port Huron

Based on these TOC interviews and findings from them, the CAR team has aggregated the most pertinent information and summarized it below.

TOCs value data that can be acted on in real time. Currently, the task of monitoring pertinent data and acting on it is largely manual. Traffic operators monitor reported traffic speeds and CCTV cameras, but many issues are not captured by cameras.¹ Operators often rely on police dispatch and agency field personnel to keep the TOC updated on road conditions. Most TOC representatives expressed challenges in getting timely accurate information across coverage zones. One operator specifically lamented that it was particularly difficult to determine when incidents have been cleared and/or traffic conditions have returned to normal. TOC representatives were universally interested in using crowdsourced data to supplement existing practices, and many have already begun to experiment with such methods.

The actions that TOCs take in response to pertinent data are almost entirely manual. Actions include adjusting DMS messages, deploying police or agency personnel, and disseminating information (e.g., through email listservs, MiDrive, Twitter, Waze, etc.). Local TOCs can also respond to traffic conditions by adjusting signal timing. Traffic operators expressed very little interest in having any of these actions automated in direct response to

¹ The MDOT Bluewater International Bridge TOC is unique in that essentially all of their area of influence is monitored by CCTV cameras.

incoming data. The format of any data is not particularly important, so long as it reaches the right people with minimal delay.

THIRD-PARTY AGGREGATED CROWDSOURCED DATA

TOCS were generally familiar with the concept of contracting with third-parties to obtain aggregated crowdsourced data. MDOT TOCs are involved with the process by which MDOT populates its MiDrive website with traffic speeds. (MiDrive data and travel time estimates given by dynamic message signs is provided via contract with HERE, whose data is partially crowdsourced via instrumented probe vehicles.) Local TOCs are aware of this arrangement, but do not have similar arrangements, and generally do not utilize MiDrive as local roads are not covered. County and city TOCs rely on CCTV cameras and general incident reporting from police and otherwise.

USING SOCIAL MEDIA FOR PUBLIC ENGAGEMENT

TOCs are aware that social networking site such as Twitter and Facebook can be valuable as a line of contact to the public. MDOT maintains a Twitter feed and Facebook page. Each of the MDOT regions also maintains a separate Twitter feed. WMTOC reported an effort to automate the tweeting of traffic issues over their feed, which compliments an email listserv.

CROWDSOURCE REPORTING FEATURE OF WAZE

The Macomb County TOC is very keen on using the crowdsourced reporting feature of the Waze Navigation app for both information gathering and dissemination. Traffic operators monitor Waze for incidents within the region and “often get incident information from Waze before we hear from police dispatches.” Macomb county TOC has also developed a department Waze map-editor account, which allows the department to share information such as road closures or construction zones with Waze users. The information posted to Waze is pushed to Google Maps, and thus both Wazers and Google Navigate users can receive information from the road commission without ever realizing they were interacting with the MCDR.²

² Any member of the public can become a map-editor on Waze. This privilege is free, but must be ‘earned’ by being a dependable contributory member of the Waze community.

The RCMC reported that they briefly talked to Waze about developing a formal relationship, but initial talks suggested that the terms of such an arrangement would be problematic.³

RCMC representatives mentioned that they considered developing a custom-built platform (similar to MiDrive) to provide traffic information, but did not envision that it would ever be as useful as existing apps like Waze and Google Maps.

TRANSPORTATION ASSET CONDITION REPORTING

The WMTOC and MCDR TOC are actively investigating methods that would facilitate citizen reporting of transportation related issues (e.g., malfunctioning signals, damaged signs, etc.). WMTOC would prefer to utilize an existing app or service platform for this purpose rather than developing a custom-built platform. Similarly, MCDR mentioned the possibility of working with SeeClickFix to allow crowdsource reporting of civil issues.

RCOC uses a custom web-reporting tool, and responds to 100-150 complaints per week. Complaints submitted via internet and phone are synthesized and incorporated into project planning and prioritization. SEMTOC asks individuals who have previously reported issues to continue to submit regular reports of their experience with the transportation system via email. SEMTOC representative also voiced concern about information overload if too many crowdsourced reports must be looked into.

THE INTERNET AS A SENSOR

All TOCS reported using the internet as a sensor in a very rough way (i.e., manually monitoring Waze or Google Maps traffic layer).⁴ Google Maps provides traffic speed information similar to that provided by HERE via MiDrive, but at a higher resolution and broader coverage. TOCs reported that they respond to congestion as reported by Google Maps by, for example, repositioning intersection cameras (MCDR) or contacting the county road commission to investigate the situation (WMTOC).

³ Several public agencies have established partnerships with Waze, such as the Florida DOT: <http://www.wfla.com/story/25596106/state-dot-partners-with-waze>

⁴ Following the interview of MCDR by CAR, MCDR staff reported experimenting with using open traffic data (MapQuest) as a virtual sensor to obtain estimated traffic speed information. As of publication of this report, it is not known if MCDR found the effort successful.

The MCDR TOC reported monitoring Waze for crowdsourced incident reporting. The WMTOC mentioned that some attempt was made to monitor Waze, but the available information overwhelmed existing resources. None of the TOCs reported using any such information in an automated way (i.e., as described in Chapter 4). One WMTOC representative lamented that there does not seem to be an easy way to use existing open data to receive alerts about relevant information.⁵

One TOC suggested that valuable information could be acquired by monitoring local police-band communications. While it is too labor intensive to dedicate TOC operators to monitor police chatter, it might prove feasible to develop voice-recognition applications that alert traffic operators to potentially relevant issues.⁶

TOCs reported utilizing the Regional Integrated Transportation Information System (RITIS),⁷ a traffic data analysis tool that can provide both real-time and archived data. RITIS can be set-up to provide email alerts when it detects traffic incidents; however, traffic operators reported that use of RITIS was very limited, in part because RITIS makes it difficult to set-up alerts that are actionable for TOCs.

DEDICATED PLATFORMS

Dedicated platforms include any platform that has been developed specifically to produce crowdsourced transportation data. Custom-built platforms have been developed in the public sector, private sector, and through public-private partnerships.

An example of a public-sector, dedicated crowdsourcing app is MDOT's new MiDrive mobile application. The MiDrive mobile app integrates with MDOT's MiDrive traveler information site to allow users to report the location of traffic issues. The MiDrive mobile application would seem to be similar to private-sector custom built platforms (e.g., Waze, Scout by Telenav) that allow similar reporting as an extension of a GPS navigation app.

⁵ Specifically, WMTOC operators would like to be able to receive email alerts when sites such as Google Maps or Waze report certain types of incidents on routes of interest. Google has an open API that could allow for such capability, but utilizing this would require manual coding from the agency end to interact appropriately with the Google API.

⁶ Many public safety bands are available via digital streams through sites such as radioreference.com.

⁷ Developed by the University of Maryland.

Representatives from WMTOC expressed that the first option when developing new methods of collecting, disseminating, or analyzing information should be to utilize an existing platform. Outsourcing the development, maintenance, and marketing of existing platforms to commercial developers sometimes allows TOCs, and more broadly DOTs, to leverage private sector innovation and expertise to supplement public resources.

One MDOT representative from a regional TOC suggested that private-sector platforms (e.g., Google Maps Traffic) are often much more useful than platforms developed for specific agency purposes (e.g., MiDrive). At least one TOC representative mentioned that Google Maps Traffic data is usually more accurate and broadly available than the traffic data provided to MiDrive by HERE.

INTEGRATING CROWDSOURCED DATA INTO EXISTING AGENCY PRACTICES

The TOCs that we interviewed generally react manually in real-time to any actionable information (with the exception of dedicated travel-time signs, which are updated automatically). Potential TOC actions include adjusting DMS, contacting police dispatch or emergency services, and contacting maintenance personnel. The Bluewater Bridge TOC responds to conditions observed on CCTV cameras by cooperating with U.S. Customs and Border Patrol Agents to optimize the number of toll/inspection booths open. TOCs perform these functions manually and are not generally interested in having these duties automated.⁸ TOCs are most interested in getting pertinent information in a timely fashion. The format of any data is not particularly important, so long as it is actionable. CCTV feeds are generally considered very useful. Email notifications are a standard practice.

⁸ As an exception, one TOC expressed interest in having Waze data integrated into the TMS. The interviewee did not make it clear if this integration should be automated or not.

APPENDIX C: LIST OF ABBREVIATIONS

3D	Three-dimensional
API	Application Programming Interface
AVL	Automated Vehicle Location
BWBTOC	Bluewater Bridge TOC
CAD	Computer Aided Dispatch
CAR	Center for Automotive Research
CCTV	Closed Circuit Television
COTS	Commercial Off The Shelf
DMAG	Data Modernization, Assurance, and Governance
DMS	Dynamic Message Signs
DUAP	Data Use Analysis and Processing
EPA	Environmental Protection Agency
FCP	Freeway Courtesy Patrol
FDOT	Florida Department of Transportation
GPS	Global Positioning System
GTFS	General Transit Feed Specification
HERE	Not an acronym. Refers to the division of Nokia involved in mapping and location data.
IoT	Internet of Things
MCDR	Macomb County Department of Roads
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
MTA	Metropolitan Transportation Authority [of New York]
MSP	Michigan State Police
MVDS	Microwave Vehicle Detection Station
NPDES	National Pollution Discharge Elimination System
PB	Parsons Brinkerhoff
POI	Point of Interest
PPP	Public-Private Partnership

APPENDIX C: LIST OF ABBREVIATIONS

RCOC	Road Commission of Oakland County
SEMTOC	Southeast Michigan TOC
STIP	State Transportation Improvement Program
STOC	Statewide TOC
TAMS	Transportation Asset Management System
TCP/IP	Transport Control Protocol/Internet Protocol
TOC	Transportation/Traffic Operations Center
U.K.	United Kingdom
U.S.	United States
WMTOC	West Michigan TOC