Sensors, Monitors & Big Data

This paper is based on work completed as part of The University of Minnesota's Transportation Futures Project. More information about The Transportation Futures Project can be found on the project homepage.

INTRODUCTION

Recent developments in technology have given us the opportunity to become increasingly connected and, as a result, many of our day-to-day activities can in some way be translated into data. With a smartphone in their pockets, users can stay in touch with friends across the world, shop, manage their schedules and trade stocks. Smartphones also assist with transportation activities, and allow a user to plan a route, locate the nearest car-share vehicle, hail a ride, compare gas prices at nearby stations, rent a bicycle, and check on the arrival of their bus. Additionally, transportation agencies use sensors and monitors to track system conditions in real time and alert drivers of crashes ahead of them or travel time to destinations. Users are not the only recipients of data. Information on the location and behavior of the user can be communicated back to transportation providers, and in turn made available to the public in large data sets to help improve transportation services.[1]

Connected vehicles also offer the potential to collect significant amounts of data based on their ability to communicate travel patterns directly with databases through wireless internet connections. A recent study commissioned by the Michigan Department of Transportation discussed some of the benefits and challenges of using connected vehicle data to assist in travel demand modeling activities. Connected vehicles and the data collected from them offers opportunities for greater efficiencies and logistics management, as well. The increased granularity of data from connected vehicles and the potentially widespread availability are two positives, while sampling bias toward wealthier individuals who will be able to afford new connected vehicle technologies in their early days remains a concern.[2]

The collection, analysis, and sharing of this so called "big data" can have profound impacts on the transportation network. It has the ability to make getting around easier, and can improve the service and reliability of transportation providers and services. These data-collecting devices can also be used for personal monitoring of health and exercise behaviors—which can influence transportation behaviors. Devices that tell us information about ourselves and other devices that inform transportation professionals both have effects on travel choices and behavior. This paper will discuss available technologies, the information that is collected, and some of the potential impacts this information has on the future of transportation.

DATA FOR THE TRANSPORTATION NETWORK

A broad collection of data is available to professionals working to improve the ways that people and goods move around the country using many modes. This discussion would be incomplete without time devoted to *how* this data is collected. Mobile technologies like smartphones, GPS systems, tablets, and connected vehicles provide substantial amounts of data that describe the ways in which people move from place to place.

Data related to traffic flow and volume can be collected for all modes. Some techniques are more sophisticated than others, but all share the goal of increased understanding of the transportation network—what is going on, when, and where it is happening. This data helps transportation providers make the network safer, more reliable, and more efficient.

Motorized Traffic

Motor vehicle traffic is counted by varying jurisdictions and used to allocate funds, improve safety, and mitigate congestion. On MnDOT roads, vehicle counts are taken at approximately 33,000 locations. There are a number of technologies that exist to count vehicular traffic.

- Pressure sensors permanently installed beneath the road surface continuously count traffic as vehicle pass over them.

[1] NY MTA
[2] Walker et. al., 2015

- **Pneumatic tubes** are installed on the road surface for short durations and on a rotating schedule. Frequently used along with the permanent pressure sensor counts, these short duration counts can be extrapolated to provide jurisdictions with average annual daily traffic (AADT)—a measurement of average traffic on a particular road segment. Using a combination of the tubes and the pressure sensors, vehicle types can be distinguished as well as the weight and speed of the vehicle.[3] These characteristics of vehicles can help determine the amount of freight moving on roads.
- **Wireless traffic sensors**, although more costly up front, can be placed in the pavement with greater ease than pressure sensors, limiting the time a section of roadway must be closed. Resembling hockey pucks, these sensors can be set up in a variety of configurations in the roadway, which can provide different data related to vehicle type and speed. Supporting infrastructure around the wireless sensors allow for data to be instantly sent to analysis software, instead of being downloaded and collected in the field.[4]

Non-motorized Traffic

Adequate knowledge of where and when people are biking and walking is important when planning for non-motorized transportation users. This information helps plan facilities and infrastructure that increase safety, convenience, comfort and connectivity for those who choose these modes. Knowing the intensity and location of bicycle and pedestrian traffic also informs where investments should be made. For transportation providers with limited funding, this is especially important. For years, the vast majority of bicycle and pedestrian counting initiatives have relied on time and personnel-intensive manual counting efforts. Now, several established and emerging traffic counting vendors offer a variety of automated technologies to accurately count the number of people biking and walking.

- **Inductive loops** are made from wrapped wires which are embedded in the pavement. A small alternating electrical current runs through the wire until a magnetic object passes over it, disturbing the magnetic field.[5] When the field is altered by the bike, it signals a simple counting mechanism which tallies the rider. The data from the counter can be downloaded or wirelessly transferred to a server for analysis.
- **Pneumatic tubes** are narrow rubber tubes that sit on the pavement surface. When a bicycle rides over the tube, a small burst of air travels from the point of contact to the end of the tube, which is connected to a pressure sensor that registers the burst as a cyclist. Similar to the inductive loops, the counts are tallied and can be downloaded from the system.
- **Infrared sensors** can be mounted perpendicular to the path of travel and count bicyclists or walkers using infrared heat detection, or when a traveler crosses through a laser beam projected across the travel area by the device.
- **Smartphone apps** like Strava allow people biking, walking and hiking to track their routes and show popular routes and segments that have been traveled by other users of the app.[6] Other online tools like Cyclopath (only available in Minnesota) allow bicyclists to post comments about favorite routes, hazards, and obstacles to an editable map for others to explore.[7]

New Technologies

Previously, video recordings offered an accurate depiction of street movements, but required a labor intensive process of reviewing all video and counting vehicles, bicyclists, or pedestrians. New technologies are becoming available that automate counting by using sensors and existing camera feeds to provide more accurate data of all traffic along a street.[8] These systems are able to distinguish between different modes and determine how the network is affected by changes such as street closures or special events. Advances in wireless sensors have the ability to distinguish between bicycles, transit vehicles, and passenger vehicles. These sensors can also be programmed to send a green-light-request to traffic signals when a bus is present, which has the ability to make transit more reliable and efficient.[9] Connected vehicles also offer the potential to collect information about how vehicles move throughout communities and the state at a level of detail that is difficult to attain with current methods.

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[3] MnDOT
[4] Sensys Networks
[5] FHWA
[6] Strava, 2016
[7] Cyclopath, 2016
[8] Evans-Cowley, 2015
[9] Sensys Networks

Technologies can also be used to gather data used for parking management. Sensors embedded in ground at parking stalls and in parking meters can detect whether a parking space is occupied and paid for. This data can be fed to the public through smartphone applications to alert drivers searching for a parking space. Using occupancy and payment data, parking management professionals can adjust parking prices to achieve the desired availability of parking. If parking at meters in one area of the city is overly abundant, it may indicate the price is too high and should be adjusted. Conversely, if metered parking is unavailable in another area of the city, it may indicate parking is underpriced. The use of these technologies allow cities to limit the amount of vehicles circulating looking for parking.[10]

Monitors may also be used in law enforcement. Advances in license plate recognition and traffic violation cameras allow detection when a vehicle is speeding or violating a red light. The system can then take a photo of the vehicle and recognize the license plate. This technology has unresolved privacy issues. Minnesota does not use red light and speed cameras, though they are used in 24 U.S. states, the District of Columbia, and the U.S. Virgin Islands.[11]

Smartphones are arguably the most important transportation innovation of the decade.[12] Many trips begin with their use—relying on apps and maps to direct the user to their final destination through services like 511MN and other proprietary offerings from Google and Apple. Users might also rely on apps to check gas prices before heading to the pumps. For example, users of some car-sharing systems have the ability to find a nearby car for rental, locate it, and unlock the car using just their smartphone. Cities are allowing open access to transportation data to give third party and private software developers the opportunity to create smartphone apps for a more predictable transportation network. The goal of many developers is to create an app that puts all transportation choices, including their cost and trip time, into one single app. Many products—including OMG Transit (produced by developers from the Twin Cities) and RideScout—offer varying levels of this service across the U.S. In San Francisco, where its app is most robust, RideScout offers transit, bike share, scooter share, and car share options all integrated into a single app. RideScout is not yet available in the Twin Cities, but currently is under development. OMG Transit offers much of the same functionality as RideScout.[13] As these apps continue to evolve users will not be the only ones to benefit. It's not unrealistic to imagine a future that includes mobile ticketing where passes, tickets and rentals are stored and completed on the smartphone. Transportation providers will have an even more robust source of data about movement and mode use. This data can be used to better site bike-share docks to accommodate bus riders on their last mile home.[14] The back and forth of information between providers and users will continue to improve the services and experiences.

GPS-enabled smartphones also act as their own monitors of traffic. Software like Google Maps aggregates smartphone location and movement data from active drivers to inform other drivers of congestion, accidents, and detours. Users of the app Waze can act as a community by self-reporting these obstacles—which provides a source of information besides via a transportation agency. Other companies like AirSage collect anonymized cellphone and smartphone data over long periods of time to determine approximate home and work locations based on device pings.[15] That data is then sold to transportation planning agencies to better describe the general travel patterns within a city, county, region, or state.

DATA FOR THE INDIVIDUAL

Just as sensors and monitors can be used to track movement on the transportation network, personal activities and behaviors can be tracked to help people meet their health and fitness goals. Data reported on the individual is broadly part of the notion of the "quantified self"—the idea of collecting data on oneself to promote healthier and more sustainable living. With the technology available and more being developed, it is no longer necessary to rely on generic information. Instead, a user is able to receive personalized data that is tracked automatically, as opposed to self-tabulated and counted. Fitness trackers are devices or software that collect and report data related to activity and behaviors. Often worn on the body, they can track heart rate, walking distance, calorie consumption, and quality of sleep. They are widely available and can wirelessly transmit the data to software applications, where it can be viewed and analyzed. Because this data can lead to changes in transportation behavior (e.g., someone walks instead of drives in order to meet their fitness goals), it has the potential to impact the transportation network.

[10] SFpark
[11] Governors Highway Safety Association, 2016
[12] Goldwyn, 2014
[13] OMG Transit, 2016
[14] Goldwyn, 2014
[15] AirSage, 2016

Benefits and Considerations

Travel and fitness tracking devices and software can be used as an intervention tool to promote mode shifts in transportation behavior. A device could incorporate three strategies into producing behavior shits:[16]

- Awareness: messaging from the device or software tells the user how much carbon is produced from using a particular mode of transportation.
- Motivation: messaging from the device or software tells the user about the monetary costs or health impacts associated with one mode over the other.
- Action: messaging from the device or software provides the user with implementable steps to achieve changes in travel behavior. The messaging could detect a trip on one mode and offer different options for that same trip made through different modes.[17]

These devices, paired with smartphones, offer opportunities to develop efficient, low cost, and innovative approaches to collecting and sharing travel behavior data as well as promoting sustainable travel choices and mode shifts.[18]

HACKING & DATA PRIVACY

In recent years, data available to transportation users and transportation professionals has grown significantly—largely because of the availability of smartphones. Sixty-four percent of American adults currently own a smartphone of some kind, up from 35 percent in 2011.[19]

Beyond transportation, data can be "mined" from several other sources, which can be used in targeting advertisements to consumers. Users of technology are now marking themselves across geographic space with every phone call, email, text message and credit card purchase they make. With the amount of data being collected and transmitted, there is a concern over privacy and the use of this data. In February 2012, the White House introduced the Consumer Privacy Bill of Rights, which aimed to give the public control over personal details collected by companies. However, in February of 2016, the same document has failed to produce new data controls.[20] It remains to be seen how advances in technology and connection will be balanced with innovation, regulation, and privacy. There is no doubt that rich data can improve the services that are delivered to the transportation network. Continuing development of the technologies that collect information will need to be balanced with the costs associated with security and privacy. Two key concerns are highlighted in this section – vehicle hacking and data generation and storage.

Vehicle Hacking

The emergence of internet-connected vehicles has spawned a new concern related to the ways in which people travel: the potential hacking and remote control of personal automobiles.[21] What once might have seemed like something that could only happen in the distant future hacking is now possible and has been demonstrated through tests on Chrysler-made vehicles.[22]

In the past, hackers have proven their ability to override and take control of vehicle systems through hard-wired connections to computers in an automobile. With the emergence of telematics systems (internet-connected automobile services) in cars comes the opportunity for hackers to remotely locate, track, or connect to a vehicle.[23] Common examples of telematics systems include Chrysler's Uconnect, GM's Onstar, Toyota's Safety Connect, and others. The potential implications of this vulnerability are vast, and the demand for connected vehicles seems to currently be outpacing the speed at which new, robust security measures are implemented in vehicles. Senators Edward Markey (MA) and Richard Blumenthal

[16] Levinson, D. et al. "The Transportation Futures Project: Planning for Technology Change." , Minnesota Department of Transportation Research Services & Library, 2015.
[17] Ibid.
[18] Ibid.
[19] Smith, 2015
[20] Singer, 2016
[21] RAND Corporation, 2014
[22] Greenberg, 2015
[23] Ibid.

(CT) introduced the SPY Car Act of 2015 in July as a way to impose more stringent cybersecurity standards on auto-makers; however, the bill has not progressed beyond its initial reading.[24] The SPY Car Act would require the NHTSA (National Highway Traffic Safety Administration) and FTC (Federal Trade Commission) to establish performance standards for vehicle-makers that include hacking protection, data security, and hacking mitigation, while also creating a "cyber dashboard" that would display the security rating on every new car for sale.[25]

Data Generation & Storage

Beyond the potential for a vehicle to be hacked, there are significant questions about the fate of data that will be generated by autonomous and connected vehicles as they enter the consumer marketplace.[26] The number of different businesses or organizations who might be interested in data about a trip, vehicle, or passenger is quite long. Insurance companies, nearby commercial retailers, and law enforcement agencies may all want to know about a person or vehicle's location, destination, travel patterns, and more.[27] Storing the voluminous amounts of data that will be produced by these practices will be a challenge, as will ensuring that data remains up to date and is accessible by the appropriate parties.

It seems likely that most data generated from autonomous vehicles would be stored in a cloud-based system of some kind. Developing security measures for these systems will be of critical importance. Another important consideration is who might be liable for data should a breach occur. Will data be anonymized appropriately to protect consumers? Many questions about how the data-driven "back-end" of autonomous vehicles will function in the marketplace have yet to be answered. The SPY Car Act addresses some of these issues, by directing the FTC to establish standards for transparency in where data is collected, used, and processed, establishing opt-out opportunities for consumers, and prohibiting the use of driving data for marketing purposes without user consent.[28]

FUTURE OF SENSORS, MONITORS AND BIG DATA IN TRANSPORTATION

With technology and innovation increasing at such rapid rates, it is becoming easier than ever before for transportation providers to monitor and collect data on the network. This data can help the system become more reliable and predictable for both the provider and the user. The practice of sharing this so-called big data publicly has allowed public transportation agencies to provide more information to their customers by using software developers to create ways of displaying and communicating the information. Many smartphone apps use up to the minute transit agency data to provide the customer with the most accurate schedule for their bus, and these apps are often the product of third party developers, instead of the transit agency itself. Furthermore, planning for non-motorized traffic will continue to advance because of advances in counting technologies. This is also true for motorized vehicle counting and communication between them; not only do drivers and providers know where vehicles are moving, but also the speed and time at which they are traveling. Finally, the individual users of the network continue to gain information about their health and activities through wearable technology and reporting, which has the power to encourage behavior changes related to transportation.

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[24] S. 1806
[25] Senator Edward J. Markey, 2015
[26] RAND Corporation, 2014
[27] Anderson et. al., 2014
[28] Senator Edward J. Markey, 2015