PARSONS BRINCKERHOFF

MDOT
Michigan Department of Transportation

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CENTER FOR AUTOMOTIVE RESEARCH

USE OF DATA FROM CONNECTED AND AUTOMATED VEHICLES FOR TRAVEL DEMAND MODELING

October 29, 2015

Michigan Department of Transportation

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Abstract:
Travel demand modeling is a crucial component of transportation planning and system management. Unfortunately, creating an accurate model of network traffic patterns can be difficult and time consuming. The calibration and validation of travel demand modeling requires the use of extensive datasets that describe the travel characteristics of people in the modeling

area. This study investigates the potential use of connected and automated vehicle (CAV) data for both statewide and regional-level modeling. While there are related privacy and data management issues to overcome, the data collected from CAVs holds great promise for supporting travel forecasting modeling, transportation system management and planning.

EXECUTIVE SUMMARY

Travel demand modeling is a crucial component of transportation planning and system management. Unfortunately, creating an accurate model of network traffic patterns can be difficult and time consuming. The calibration and validation of travel demand modeling requires the use of extensive datasets that describe the travel characteristics of people in the modeling area, including origins and destinations, trip duration and frequency, mode choice, and other parameters. This data are typically collected through household surveys conducted as part of model updates, as well as drawn from the American Community Survey (ACS) when model updates are close to the census years. The household travel survey is costly and complex to obtain, and represents a small sample of travelers in a region, making model calibration more challenging. Furthermore, as a household travel survey requires participants to log their activities after the fact, and resulting data must be geocoded, there is an inherent potential for errors during coding. These transportation planning functions are also supplemented with data from Permanent Traffic Recorders (PTRs) and other traffic count sources which include information on vehicle classifications to gauge fleet composition in the network and different travel characteristics between fleets.

Connected and automated vehicle systems have the potential to deliver travel data vital to model calibration, in near real-time, for the entire equipped system, and without requiring any action from the traveler. However, should the related privacy concerns be overcome, the practicality of capturing, managing and processing the data required for travel demand modeling is still not well understood. CAR and Parsons Brinckerhoff research team interviewed MDOT and SEMCOG stakeholders to evaluate current modeling practices and data gaps, and investigate the potential use of this data source for both statewide and regional-level modeling. While there are related privacy and data management issues to overcome, the data collected from CAVs holds great promise for supporting travel forecasting modeling, transportation system management and planning.

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1 INTRODUCTION

Travel forecasting is a crucial component of transportation planning and system management. Unfortunately, creating an accurate model of network traffic patterns can be difficult and time consuming. The calibration and validation of travel forecasting models requires the use of extensive datasets which describe the travel characteristics of people in the modeled region, including, but not limited to, trips by trip purpose, trip origins and destinations, trip duration and frequency, mode choice, and path choice.

This data is typically collected through household travel surveys conducted specifically to support model updates, as well as drawn from the National Household Travel Survey (NHTS) and the American Community Survey (ACS). The NHTS is not only costly and difficult to obtain, but it also represents a small sample of travelers in the modeled region, limiting the level of disaggregation possible for several model components, and making model calibration more challenging. The complexity of recording, collecting, coding, and geo-locating household travel survey data may also lead to inconsistencies and potential errors in the final data set. In fact, research shows that households consistently underreport trips when comparing trip recorded in the travel diary as compared to trips recorded by the Global Positioning Satellite (GPS) unit for GPS using households.

Travel model development includes the key steps of model estimation, calibration, and validation. Household travel surveys largely support model estimation and calibration, whereas model validation uses other data sources. For example, validation of highway trip assignment is supported by traffic count data from Permanent Traffic Recorders (PTRs) and other traffic count sources that can include information on vehicle classifications to gauge fleet composition in the network assignment for advanced models with a truck component. These count data, however, do not provide information that would better inform truck model development, such as the trip length distribution for trucks by truck type, or average vehicle miles traveled by truck type.

There is clearly room for advancement in the collection of data needed to support travel model development and other transportation planning activities that rely on the output from travel models. One such source that offers a great deal of potential is Connected and Automated Vehicle (CAV) systems. CAVs can be described as vehicles with the potential to deliver real-time data, for the entire equipped system, without requiring any action from the traveler. While there are related privacy and data management issues to overcome, the data collected from CAVs holds great promise for supporting travel forecasting modeling and transportation.

Specifically, the study is to help transportation planning agencies, including the Southeast Michigan Council of Governments (SEMCOG) and Michigan Department of Transportation (MDOT), understand and benefit from CAV data with respect to their travel forecasting models. This report includes the following:

- Overview of CAV including definitions, applications and data
- Summary of the input of travel forecasting modelers and developers, including costs of current collection processes and deficiencies in traditional data sources
- Data gaps that would not likely be filled using CAV data
- Discussion of potential impacts of CAV data and challenges
- Viability of using CAV data as a ground-truth count source

2 OVERVIEW OF CONNECTED AND AUTOMATED VEHICLES

Before identifying methods to use CAV data in travel forecasting modeling applications, it is important to provide an overview of these systems, including definitions as well as how these technologies will work.

2.1 DEFINITIONS

Connected and automated vehicles should be differentiated. Connected vehicles are equipped with technology that enables the communication between vehicles, infrastructure, and a consumer via wireless devices. The backbone technology for connected vehicle safety applications is dedicated short-range communications (DSRC), a low-latency licensed radio frequency in the 5.9 GHz band currently allocated for transportation use only. Depending on the application, there may be radio units in vehicles and on the roadside.

There are two primary means of communication. The first is vehicle-to-vehicle (V2V) which enables vehicles communicating with each other by passing data from one vehicle to another. Much of this revolves around vehicular safety. The other type of communication is vehicle-to-infrastructure (V2I). In this scenario, data passes back and forth between vehicles and infrastructure. This may include the use of cellular and /or Wi-Fi networks as well as at fixed roadside locations to facilitate the communication.

In a connected vehicles environment, each vehicle acts as a sender, receiver, and router to broadcast information to the vehicular network or transportation agency, which then uses the information to ensure safety and smooth operation of traffic. The level of connectivity is determined by two groups of factors: (1) those related to the traffic stream, such as traffic flow (density) and market penetration; and (2) others related to the technology itself such as the transmission range and interference caused by infrastructure.[1]

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[1] Osman, O. and S. Ishak. Accounting for traffic density and market penetration in a newly developed connectivity robustness model for connected vehicles environments. 93rd Transportation Research Board Annual Meeting January 12-16, 2014

The range of applications for connected vehicles is numerous. Figure 1 summarizes various safety, mobility and environmental applications from the United States Department of Transportation.

TABLE 1: CONNECTED VEHICLE APPLICATIONS[2]

V2I Safety
- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Spot Weather Impact Warning
- Reduced Speed/Work Zone Warning
- Pedestrian in Signalized Crosswalk Warning (Transit)

V2V Safety
- Emergency Electronic Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Left Turn Assist (LTA)
- Blind Spot/Lane Change Warning (BSW/LCW)
- Do Not Pass Warning (DNPW)
- Vehicle Turning Right in Front of Bus Warning (Transit)

Road Weather
- Motorist Advisories and Warnings (MAW)
- Enhanced MDSS
- Vehicle Data Translator (VDT)
- Weather Response Traffic Information (WxTINFO)

Environment
- Eco-Approach and Departure at Signalized Intersections
- Eco-Traffic Signal Timing
- Eco-Traffic Signal Priority
- Connected Eco-Driving
- Wireless Inductive/Resonance Charging
- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Traveler Information
- Eco-Ramp Metering
- Low Emissions Zone Management
- AFV Charging / Fueling Information
- Eco-Smart Parking
- Dynamic Eco-Routing (light vehicle, transit, freight)
- Eco-ICM Decision Support System

Agency Data
- Probe-based Pavement Maintenance
- Probe-enabled Traffic Monitoring
- Vehicle Classification-based Traffic Studies
- CV-enabled Turning Movement & Intersection Analysis
- CV-enabled Origin-Destination Studies
- Work Zone Traveler Information

Mobility
- Advanced Traveler Information System
- Intelligent Traffic Signal System (I-SIG)
- Signal Priority (transit, freight)
- Mobile Accessible Pedestrian Signal System (PED-SIG)
- Emergency Vehicle Preemption (PREEMPT)
- Dynamic Speed Harmonization (SPD-HARM)
- Queue Warning (Q-WARN)
- Cooperative Adaptive Cruise Control (CACC)
- Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
- Emergency Communications and Evacuation (EVAC)
- Connection Protection (T-CONNECT)
- Dynamic Transit Operations (T-DISP)
- Dynamic Ridesharing (D-RIDE)
- Freight-Specific Dynamic Travel Planning and Performance
- Drayage Optimization

Smart Roadside
- Wireless Inspection
- Smart Truck Parking

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Automated vehicles, on the other hand, use sensors (such as cameras, RADAR, LiDAR, or ultrasonic), positioning systems, and sometimes connectivity to gather information and perform some or all driving functions (e.g., lane departure warning, emergency braking, and adaptive cruise control) without direct control from the driver. Automated vehicles are often referred to as "self-driving vehicles."

Some studies suggested that there is a continuum between conventional, fully human-driven vehicles and automated vehicles, which partially or fully drive themselves and may require no driver at all. NHTSA has created a hierarchy to help clarify this continuum.

[2] http://www.its.dot.gov/pilots/cv_pilot_apps.htm

- Level 0 (no automation): The driver is in complete and sole control of the primary vehicle functions and is solely responsible for monitoring the roadway and for safe vehicle operation.
- Level 1 (function-specific automation): The driver has overall control but can choose to cede limited authority over a primary control (e.g., adaptive cruise control).
- Level 2 (combined-function automation): This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of controlling those functions.
- Level 3 (limited self-driving automation): Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions, and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control.
- Level 4 (full self-driving automation): The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. By design, safe operation rests solely on the automated vehicle system.

The level-4 automation systems currently being developed will require some means of connecting to the internet for map information, software updates, and access to live information such as traffic conditions. Prototype automated vehicles are not dependent on DSRC or wireless access in a vehicular environment (WAVE) systems. However, many stakeholders within the ITS industry believe that DSRC/WAVE connectivity will be required to achieve reliable fully automated (driverless) systems. Additionally, some researchers believe that no single technology is capable of simultaneously attaining the accuracy and availability specifications required for lane-level positioning in the expected automated driving environments.[3] The solution will likely be a combination of different technologies (GPS, DSRC, Inertial Navigation

[3] Transportation Systems Research Group, College of Engineering – Center for Environmental Research and Technology (CE-CERT), University of California, Riverside (UCR). Connected Vehicle Technology Challenge: Lane-Level Vehicle Positioning using DSRC as an Aiding Signal. 2008 https://s3.amazonaws.com/challengepost/zip_files/production/1270/zip_files/Connected%20Vehicle%20Challenge%20DSRC-positioning.pdf. Accessed on August 28, 2015.

System or INS, and automated sensor-based mapping) necessary for lane-level safety applications (e.g., curve speed warning and lane departure warning).[4]

While automated vehicles' dependence on dedicated infrastructure is much lower than it was in the early prototype stages several years ago, they may still need some basic level of infrastructure including road markings, signage, and some level of V2I communications. Some studies suggest that lack of infrastructure could be a challenge to accelerating penetration of automated vehicles.

2.2 AVAILABILITY OF CAV DATA

Connected and automated vehicles are expected to generate a large volume of data; however, the data generated varies by each. Connected vehicles will continuously transmit a huge range of information on:

- Location/Heading/Speed
- Acceleration
- Transmission state
- Vehicle length/width
- Brake system status
- Path history
- Outside air temperature
- Wiper activations

Automated vehicles also provide a wealth of information, though the type of data generated by an automated passenger vehicle depends on the level of automation supported. In fact, the degree to which a vehicle must perform "sense-assess-act" functions is correlated to the level of automation and determines the type and amount of data collected, processed, and utilized by the vehicle. The primary data component produced by automated vehicles is three-dimensional digital image data, which concurrently enables the operation of the automated driving system. The data collected or generated by an automated system are primarily related to the host vehicle's surrounding environment, current state of the host vehicle, and decisions made by the automated system.

[4] U.S. DOT, FHWA. Mapping Technology Assessment for Connected Vehicle Highway Network Applications. Presented at CGSIC, Seattle, Washington, August 2012.

2.3 ADDITIONAL TYPES OF VEHICLE CONNECTIVITY

Most modern vehicles are already equipped with various wireless connectivity that is able to provide endless vehicle and operational information. These technologies include in-car plugins, in-car infotainment systems, cellular connectivity, and insurance connectivity.

IN-CAR PLUG-INS

Various adapters are being offered today that connect to the standard diagnostics port (OBD-II) that is typically located under the steering wheel in most vehicles. Once connected to the cars 'computer', the adapter is able to track the vehicles' speed, miles traveled, fuel use, GPS location (the plug-in device can determine this on its own), and vehicle health. The adapter may connect via Bluetooth to the driver's mobile device and can be utilized with various apps that the user can download. Various applications include being able to get notifications when the car enters or leaves a specified geo-fence, limiting the usage of mobile devices while driving, monitoring parking location, diagnosing engine problems, giving tips on fuel efficient driving habits, and calling for help in a crash.

Third party apps may be utilized to make vehicle connectivity possibilities near endless (e.g., Automatic).[5] The app that comes with the Mojio device searches for parking as the vehicle nears its destination, gas stations when the tank is low, and for alternate routes that avoid traffic.[6] Not all plug-in devices use Bluetooth. The Audiovox Car Connection and Mojio device use their own 3G networks. The Delphi Connect plug-in uses a cellular network with a 4G LTE hotspot (optional) and Bluetooth to connect to the cloud and other devices. With some of these plug-ins, smartphones can be set up to be used as key fobs to unlock cars, and start engines.

IN-CAR INFOTAINMENT SYSTEMS

Though nothing new, in-vehicle infotainment systems like Sync, UConnect, MyLink, and OnStar continue to play a large part in vehicle connectivity today. Users can pair their mobile devices via Bluetooth so that music, messages, and phone calls may be accessed through the vehicle. Increasingly, OEMs are making apps available either of their own making or third party

[5] https://www.automatic.com/apps/
[6] https://www.moj.io/

apps like Pandora or Weather Channel. Hands free technology has gained popularity so as to let drivers control media via voice commands. When fuel is low, nearby gas stations can be located on navigation centers and may be set as destinations. The driver may also use the navigation to search for entertainment or restaurants and make reservations (by calling with their paired device). With some infotainment systems, iphone users are able to access Siri directly through the vehicle to provide endless information. In the event of a crash, some vehicles may be able to send out 911 assists either on their own or through the driver's mobile device. Airbiquity is a company that develops infotainment systems for OEMs to provide a high-performance connected car program.[7]

CELLULAR CONNECTIVITY

Today we are seeing more cellular networks get involved in connected vehicle technology. Just recently, AT&T announced that it would be partnering with Autonet Mobile (an internet –based telematics and applications service partnered with Fiat Chrysler, General Motors, Maserati, Subaru, and more) in providing 4G LTE wireless to vehicles. Autonet Mobile says having AT&T Mobility will also be beneficial in providing over-the-air software updates.[8] Last year AT&T developed its 'Drive Studio', an innovation center devoted to connected cars. AT&T already has an agreement with Audi to provide 4G LTE to all of its 2016 model year vehicles equipped with Audi connect. Finally, AT&T is going further and looking into vehicle-to-home connectivity, and vehicle-to-mobile connectivity that would allow doors to be locked, and lights and heating systems to be turned off from the car.

INSURANCE CONNECTIVITY

Another application of connected vehicle software has been to inform insurers. For example, Allstate has a plug-in device called Drivewise that collects driving behaviors (details described above in the plug-in section). A similar device is utilized by Progressive called Snapshot. Similarly, State Farm has a partnership with Hughes Telematics to develop CV technology. Together they developed a plug-in device that can call for emergency response, enable roadside assistance, give maintenance reminders, and provide other safety features.

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[7] http://www.airbiquity.com/
[8] http://www.autonetmobile.net/connected/

3 OVERVIEW OF EXISTING TRAVEL FORECASTING DATA SOURCES AND DATA GAPS

This chapter provides an overview of existing data sources and data gaps. It includes a summary of current data sources for travel forecasting models including data sources used in models for SEMCOG and MDOT followed by existing data gaps described by each agency.

3.1 GENERAL DATA SOURCES FOR TRAVEL FORECASTING MODELS

The level of complexity of travel forecasting models varies from agency to agency. As a result, the type and amount of data used to estimate, calibrate, and validate those models can vary widely. A few of the key sources used in many travel forecasting models are described below.

- American Community Survey: The American Community Survey (ACS) has been in existence for the last 15 years and was developed to replace data previously collected through the Census Bureau's decennial long form. The data is reported in 1-year, 3-year, and 5-year estimates and includes a variety of variables which are especially helpful in the trip generation and trip distribution steps of a travel forecasting model.
- Household travel survey: A household travel survey is used to collect information about the travel characteristics of households in a region. Data is collected from a sample of households in which the travel of each person in the household is documented in detail for a designated day. Information such as start time and end time of trip, origin and destination locations, trip purpose and mode are recorded. In addition, general information about the household is recorded such as number of persons, number of workers, number of children, number of autos, household income, employment status, and age. This type of survey is usually the major source of information for developing a set of travel forecasting models to estimate travel behavior in a region.
- Transit on-board survey: On-board transit surveys are often performed to complement and enhance the data and information obtained in a household travel survey. The data is considered to be "choice-based" rather than random, given the emphasis placed on a single mode. Typically, riders are interviewed with respect to their current trip.

Information such as the origin, destination, boarding and alighting locations, transfer characteristics, trip purpose, fare-class utilization, auto ownership and income are all collected from the participant while on board. On-board transit survey data can be useful in a variety of contexts including short-term or operational planning exercises as well as model development, calibration, and validation.

- 24-hour classification counts: Classification counts are useful when developing a truck component of a travel forecasting model. The counts can be used to validate truck (and auto) assignments in the model.
- Travel time information: Travel time information can be useful in both macro and micro models. Within travel forecasting models, the travel time data can be used to validate modeled free flow and congested speeds.
- Commercial vehicle / truck surveys: Truck surveys are used to collect information about truck characteristics and goods movements. Commercial vehicle surveys are used to collect information on the characteristics of commercial vehicles. Truck surveys are most often conducted to support statewide and regional models, but the data can also be useful in developing a truck generation and distribution component within a Metropolitan Planning Organization (MPO) model. Commercial vehicles are one of the most misunderstood components of MPO travel models, and a quality commercial vehicle survey can be useful to better understand travel related to these vehicles.
- External surveys: External surveys provide information for travelers that have one end of their trip outside the study region or subsequently for travelers that have both ends of their trip outside the region, but simply pass through. Travelers are asked to provide origin and destination locations, trip purpose, auto occupancy and some information on other trips made while in the region. A survey of this nature allows complementary models to be developed for two trip purposes related to external trip making including through trips, and internal-external/external-internal trips. New innovations in mobile phone data collection have proven to be a useful source of passively collected data for understanding external travel.
- Origin-destination (OD) data mining: Using confidential mobile phone records (also referred to as passive data collection) available from third party vendors, origins and destinations can be identified. These

vendors have an agreement to purchase data from the mobile phone providers (AT&T, Sprint, Verizon, etc.). This data is anonymous and cannot be tracked to individual users.

3.2 EXISTING MDOT AND SEMCOG MODELING DATA SOURCES

Individual meetings were held in June 2015 with members of MDOT and SEMCOG to identify existing data sources used by each agency for their travel forecasting models as well as data gaps that exist when developing and/or calibrating those models.

EXISTING MDOT DATA SOURCES

Representatives from MDOT discussed their data sources to develop and/or calibrate their travel-forecasting model. MDOT noted that their passenger transportation division is currently considering a statewide transit on-board survey (in part to feed some of the economic modeling being conducted), but to date the costs are simply too high and additional funding needs to be identified. In the meantime, MDOT is increasingly relying on third-party data sources such as HERE, RITIS, etc. A summary of key data sources is shown in Table 2.

TABLE 2: EXISTING MDOT DATA SOURCES

Data	Use	Comments
Household Travel Survey	Travel behavior	Conducting statewide survey in 2015. Previous survey conducted in 2004-2005
Census data	Primary socio-economic data	
REMI forecasts	Population, employment, and household forecasts	
Employment	Trip attraction model	MDOT has developed their own employment database
Origin-destination survey		Not relying on older survey data used by SEMCOG

EXISTING SEMCOG DATA SOURCES

SEMCOG staff identified multiple data sources to support their travel modeling work. It was noted that each of the main travel surveys conducted by the agency costs approximately $1M, and are done at various intervals in the model update cycle. Table 3 presents a summary of these sources.

TABLE 3: EXISTING SEMCOG DATA SOURCES

Data	Use	Comments
Household travel survey	Travel behavior	Survey underway in 2015
Census data	Primary socio-economic data	
ACS	Used to verify and support detailed census data	
Travel time	Not used for travel forecasting model, used primarily to support Dynamic Traffic Assignment (DTA)	Previously SEMCOG conducted floating car runs to collect travel time data. Currently this data is obtained from third-party sources such as HERE and AirSage (several years ago).
Classification Counts	Model validation	SEMCOG also tracks counts conducted by local agencies, which amount to 3000-4000/year
Commercial Vehicle Survey Data	Support model validation	Very dated as it is from 1996.
Origin-Destination Data	Support model validation	Sources include AirSage and Streetlight
Internal-External Trip Survey	External model	Focused on SEMCOG model area and was conducted in 1995 (very dated).
Employment Data	Trip attraction model	SEMCOG has had challenges with employment data sources due to sensitivity of the data and inability to share with consultants / third parties.

3.3 EXISTING DATA GAPS

Gaps in existing data were also discussed at the June 2015 meetings with MDOT and SEMCOG. The focus of the discussion was on the identification of data types and sources that could be used to support and enhance the travel models for the respective agencies.

MDOT DATA GAPS

MDOT noted that there is no single source of data for developing travel forecasting models, instead, many sources of data must be compared or fused in order to get a complete data picture for the region. Specific gaps mentioned include:

- Lack of speed data for lower functionally classified roadways
- Very few data sources for understanding multimodal travel, particularly in small urban areas where MDOT is responsible for developing and maintaining models
- Tourism and recreational travel are important considerations for MDOT, and data related to the travel and seasonal characteristics of this special market are difficult to obtain.

Unlike SEMCOG, MDOT does not believe that cost is necessarily a constraint on data collection decisions or sample sizes. It is their experience that the sample sizes achieved are adequate to support their modeling work.

SEMCOG DATA GAPS

According to SEMCOG, there is no good way to address non-home-based (NHB) trips within a trip-based model. Activity Based Modeling (ABM) removes the need to explicitly model NHB trips, because travel is modeled as tours, not trips. For any model development project, a locally collected household survey is the gold standard for model estimation and calibration because the data are rich enough for the analyst to understand the full scope of travel for a household or individual. It was mentioned previously that ACS data is often used as a source of travel information to support model development. The main challenge with ACS data is that it provides information on the work trip only, therefore limiting its use for understanding non-work travel, including NHB trips.

In addition, SEMCOG noted that the cost of data drives the decisions that can be made about modeling. For instance, the average model update cycle costs around $5 million. Of that, approximately $4 million is needed to support travel surveys and data collection. The high cost of conducting the surveys limits the number of samples that can be included.

4 IMPACT OF CONNECTED AND AUTOMATED DATA ON TRAVEL FORECASTING

This chapter focuses on discussions related to using CAV data for travel forecasting. In addition to information obtained from discussions with SEMCOG and MDOT, additional feedback was obtained from members of Parsons Brinckerhoff's System Analysis Group who specializes in the development and application of travel forecasting models of varying complexity around the world.

4.1 APPLICABILITY OF CONNECTED AND AUTOMATED VEHICLE DATA IN TRAVEL FORECASTING

FOUR-STEP MODELING

Travel forecasts themselves are conducted by associating travel characteristics with socio-economic factors, and then forecasting the socio-economic data into the future and deriving resulting travel demand. CAV data alone will not include the socio-economic data which is the foundation of this process. Therefore, it was concluded by all parties that the role of CAV data would largely be limited to improving the resolution and calibration of existing travel characteristics, rather than change or replace the fundamental forecasting steps and foundational data. Further, it was observed that CAV data is likely too disaggregated for a traditional 4-step model, because those models do not simulate individual vehicles or trip chains, but aggregated travel flow. In this context, CAV data is likely to be a ground-truth source only.

At the statewide model level, CAV data would mostly support improved model validation, including trip productions, trip attractions and route choice, and would not necessarily be a wholesale replacement of other data sources, nor would it likely lead to major changes to modeling. MDOT indicated that the statewide model is pretty simple (24-hour period only, single mode, etc.), which generally meets the needs of statewide planning, and that CAV data is more appropriate in resolution for more detailed urban / operational modeling, but possibly too disaggregated for the statewide level.

ACTIVITY-BASED MODELING

Advances in travel modeling include both activity-based models (ABM) and full microsimulation models. A common thread between ABMs and current investigations into microsimulation is that rather than aggregating person travel to a traffic analysis zone, individual person or households are tracked throughout the modeling framework. CAV data has the potential to provide a rich set of disaggregate data that can be used to inform and develop these more advanced models. The key to realizing the full benefit of this data would be to develop a means for fusing this data with household travel survey data or other information that would provide the missing personal and household characteristics needed to fully inform the behaviorally based models. SEMCOG is currently planning for transition to ABM, although MDOT has not yet planned to do so for the statewide or local agency models.

4.2 SPECIFIC DATA CONSIDERATIONS

DATA SCALE AND GRANULARITY

The scale of CAV data is potentially enormous, requiring significant pre-processing and/or aggregation in order to make it usable in a travel forecasting context. The current forecasting algorithms and processing power would not support use of a data source this rich and would need to be substantially updated. Further, the depth of data at an individual vehicle level is too disaggregated for a 4-step model approach, meaning individual data points would need to be aggregated to fleet-level data in order to make it usable.

CAV data would fit better in an ABM context, but even within current ABM modeling there is a limit to the number of household types you can model. CAV data would still need to be aggregated into a smaller number of household types until the computer power and algorithms are there to handle the large disaggregated data set.

IMPACT ON TRAVEL SURVEYS

It is acknowledged that raw CAV data would not be a replacement for household travel surveys, as the data is not behaviorally rich and does not link to socio-economic data, both of which are some of the most important characteristics of travel survey data, and a critical requirement of estimating behaviorally based travel models. However, one of the biggest advantages of third party data, such as AirSage, is the vast amount of data that are available to use, allowing for the mapping and understanding of travel patterns at a very disaggregate level, which can provide important insight into travel patterns for a region, or a state. Even the most comprehensive large sample household travel survey yields only a relatively small sample of origin-destination trip observations, and the data must be aggregated to show travel patterns at a district level.

The ideal solution may be to use both household surveys and CAV together, and research into fusing these data would have definite appeal. The fusing of other data sources with CAV data should also be explored, including Census data and land use / zoning data. This information at the census block or parcel level may allow for certain demographic characteristics to be mapped to the CAV data providing greater insight into travel patterns related to these demographic characteristics.

DATA SUPPLEMENTATION

There is potential for CAV data to fill in data gaps related to path choice, long distance travel, commercial vehicles, transit, and non-motorized travel.

- Path Choice: A key benefit of CAV data is the ability to obtain path choice and routing data. While some data providers are able to track individual vehicle movements with aerial (airplane or helicopter) observations, the data is expensive and only provide a relatively small overall sample. CAV data on the other hand is continually recorded and can be tracked for longer periods of time. The benefit of this data is twofold: 1) CAV data can be used to provide insight and validation into path choice and route assignment, and 2) this data can be used in a before and after context to better understand the effect of pricing strategies on path choice.
- Long Distance Travel: An important component of travel in statewide models is long distance travel. Currently there are no comprehensive data sources that provide information on long distance travel. The last major long distance travel survey was the 1995 American Travel Survey. This has created a huge deficit of information on longer distance travel. This is an area where CAV data could potentially fill a big gap in the data. As CAV is continually connected, data for longer distance travel could be obtained and analyzed to support the development of statewide models, and in a transportation context, the influence that major seasonal venues have on seasonal travel.
- Commercial Vehicles: Many believe that commercial vehicles may be the first to utilize CAV technology. As noted previously in this document, commercial vehicle travel is one of the most difficult travel markets to understand and model, which primarily stems from a lack of data for understanding this travel market. CAV data has the

potential to provide vast amounts of travel data on commercial vehicle and truck movements which could lead to significant improvements in travel modeling.

- Transit and Non-Motorized Travel: As more regions become focused on offering travel choices, there is a greater desire to understand a full array of mode choice options. On-board surveys are useful for capturing travel specific to transit ridership, but like household surveys, these surveys are constrained by cost and sample size. For non-motorized travel there are even fewer data options for understanding travel behavior. Advanced technology that allows for the seamless tracking of person movements, whether through CAV technology or mobile phone technology that mimics CAV technology will result in a comprehensive profile of travel across all modes and all modes of access. When asked whether CAV data would support MDOT's consideration of transitioning to an ABM, the response was possibly, particularly if it meant better representation of alternative modes for the smaller MPO models.

4.3 ROLE OF CAV DATA ON RELATED MODELING PROCESSES

CAV data could also support emission and traffic operational modeling:

- Emissions Modeling: Current emissions models rely heavily on national default factors such as vehicle mix, average speed distribution by hour and roadway, engine starts per day by vehicle class and distribution by hour, trip end distribution by hour, hot soak duration, etc. Replacing these national default factors would lead to improved emissions modeling for a region and a better understanding of potential emissions reducing strategies. CAV data has the potential to provide local data for many of the key measures needed for emissions modeling. This can lead to improvements in the development of long-range plans and local decisions supported by local data.
- Operational Modeling: Unlike travel forecasting models, traffic operational models such as microsimulation or Dynamic Traffic Assignment (DTA) platforms model discrete vehicle behaviors rather than aggregated fleet behaviors. This approach aligns more closely with CAV data sources, which could have a large impact on data sourcing and calibration of these models in the near-term. In the longer term, the combination of CAV data sources and improved processing

power could push regional modeling platforms more towards the discrete vehicle modeling of operational models.

4.4 DATA MANAGEMENT AND COST

There are two interconnected aspects of CAV data management. First, CAV applications often require certain infrastructure and environment information in a variety of time scales, such as signal timing, traffic sign placements, and digital 3-D maps for reference during automated driving. There is a need to identify the information that is necessary to enable and enhance CAV applications, develop standards, and provide guidance for agencies on how to implement strategies for updating, maintaining, and disseminating the information.[9]

A variety of information about infrastructure and travel conditions can be collected by CAV enabled vehicles. However, extracting insight from the huge sources of CAV data is not trivial, as the data management pipeline could span from the collection of data, back-end server for storage and analysis, integration with other sources, modelling, visualization and analysis to its interpretation, dissemination, archiving or deletion. Big data techniques that allow the efficient processing of very large datasets are needed to address these challenges. These techniques include sophisticated algorithms, scalable storage and architecture, cloud computing, and crowdsourcing.

A summary of the characteristics of traditional and big data approaches is presented in Table 3. The Safety Pilot Model Deployment and the upcoming additional connected vehicle pilot deployments will continue to contribute valuable information on the design and implementation of management systems for dissemination of agency-owned data and ingestion of CAV generated data for agency operations.[10]

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[9] NCHRP 20-24(98), Connected/Automated Vehicle Research Roadmap for AASHTO. 2015
[10] https://www.its-rde.net/showds?dataEnvironmentNumber=10014

TABLE 4: CHARACTERISTICS OF TRADITIONAL AND BIG DATA APPROACHES[11]

	Traditional Approaches	Big Data Approaches
Data Capture		
Statistical Sampling	**Yes** Small fractions of the populations are sampled	**No** Datasets encompass nearly all of a population
Experimental Design	**Critical** Guided by theories of causation and need for statistical validity	**Less Important** Data collected for other purposes often analyzed to address new questions (repurposed data)
Number of sources	**Limited** Data come from dedicated sampling/collection	**Very Large** Crowdsourced data or "electronic breadcrumbs"—incidental, automatically or system-generated electronic records—often feed analyses
Data Management		
Storage	**Single Physical Location**	**Multiple Locations** Shared or virtual access (cloud)
Structure	**Structured** Data resides in fixed fields	**Structured and Unstructured** Some data not in fixed fields, e.g., video and text streams in addition to structured data
Data Analysis		
Analytical Approach	**Statistics** Traditional regression methods	**Data Science** Pattern recognition and machine learning in addition to traditional statistics
Number of Variables	**Limited**	**Very Large**
Processing	**Manual** People use specific tools and intuition	**Automated** Optimization routines create best-fit models

Other data management-related issues include:

- Willingness to share data / data availability: similar to census data and other data sources, privacy is extremely important. As a result, there may be severe limitations with respect to accessing the data and at what resolution the data may be available. At this time, it is unknown which company would provide the data, or if a third party vendor will emerge similar to those that sell / distribute mobile phone data.
- It is still unknown with regard to the cost of purchasing this data, and whether it would have sufficient benefit to justify the cost. According to SEMCOG, they would not want to collect this data themselves or

[11] U.S. Department of Transportation ITS JPO. The Smart/Connected City and Its Implications for Connected Transportation. FHWA-JPO-14-148. October 14, 2014

store / process raw data – they would be looking for a third-party provider from whom to purchase processed 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.[12]
- One of the mobile data providers is AirSage. It collects and analyzes anonymous location data points from over 100 million mobile devices each, providing insights into patterns of people go to, or come from, a specific location by time of day. Comparing to traditional local data sources, AirSage data counts are higher since they account for visitors as well as residents – visitors are not typically seen in traditional models. The price starts at $10,000, depending on the amount of data processed, in combination with geographic details and other selected options.[13]

4.5 UNKNOWNS AND FUTURE SCENARIOS

Based on the discussions in the workshops and interview, the potential for the use of CAV in travel forecasting models exists. There are other items noted but not explicitly discussed in the interviews. These include:

- Trip generation from distinct capture points
- Continuously updated volume data / ground truth
- Origin-Destination data for all vehicles (local residents and visitors)
- Arrival and departure times
- Trip-chaining data (multi-stop)
- Speed / travel time / congestion data
- Micro-trending data

In addition, there are other considerations and unknowns with respect to the use of CAV data, for example:

[12] MDOT and CAR. Crowdsourcing Transportation Systems Data. 2015.
[13] http://www.airsage.com/

- Would all vehicles be instrumented with CAV technology? If only some vehicles had the technology, how would that impact data reporting? Could the data be expanded to the full population of the region?
- Could roadside units / other infrastructure capture vehicle messages and archive them for transportation planning purposes?
- If data privacy was mitigated, could individual messages from a single vehicle be chained together?

At this point, it is difficult to accurately predict the amount of data, quality of data, and timeline for which the data will become available. The following section of the report outlines a couple of scenarios related to these considerations:

TIER 1: LIKELY SCENARIO

In this scenario, a more practical approach is given to the usage of CAV data.

- Availability: While the developers of CAVs indicate that the technology will be more and more common within the next five years, the availability of the data for travel forecasting models may still be at least 10-15 years away. Similar to data provided by companies producing origin-destination and / or travel time data using Bluetooth data or mobile phones, the processes for obtaining and sorting the data will take time to develop. In addition, consideration must be given to the legal processes that may evolve with respect to the privacy of the data.
- Usage: As the CAV technology evolves, the data that can be derived and summarized will evolve. Travel forecasting modelers will have the ability to guide what data is needed, but it may take time. With respect to matching driving behavior with the CAV data in an effort to replace household travel surveys, it is expected that the ability to match trip purposes against the data would be limited.
- Data Reporting: It is not known how long it will take to equip all vehicles with connected vehicle technology. In fact, it is expected to take many years to implement the technology in all vehicles on the road. As a result, a full data set for a region may not be available for many years.
- Costs: Considering the high volume of data expected to be provided, the computing power necessary to process that data, and the costs to develop those processes, it is expected that the initial costs for data

sets available for travel forecasting modelers will be high. However, as with most data sets, the price will likely decrease over time once there is some stability on the data output / products. The exception to that consideration might rest with any agency / company participating in a pilot project in which the costs for that particular data set may be reduced in exchange for execution of that project.

TIER 2: POSSIBLE "IDEAL" SCENARIO

In this scenario, a more ideal / futurist perspective is proposed.

- Availability: Assuming the statements made by the developers of CAVs that the technology is only a few years away, the data could become available within five years. This may initially be more aggregated data in the form of travel time or origin-destination data; however, this will allow modelers to begin to understand the data and limitations / accuracy of that data. Also, this scenario assumes that privacy concerns are minimal and the data is readily available at a level that doesn't aggregate it too much.
- Usage: In this scenario, the wish list of data would be fulfilled, especially with respect to finding a replacement or supplement to household travel surveys. This would indicate that trip behaviors would be associated with the data.
- Data Reporting: It is assumed that data is readily available shortly after CAVs become more common on our roadways. While initial data may be more research oriented, there are opportunities for agencies such as SEMCOG and MDOT to request access to the data early on.
- Costs: While it is not expected that the data would be free, the scenario assumes that the high volume of data is readily accessible and obtainable for all interested parties at a reasonable cost. This includes substantially reducing the cost of the data compared to the household travel surveys in which the data obtained would be similar, but sample rate could greatly increase.

5 CONCLUSION / NEXT STEPS

As noted in this report, there continues to be gaps in data related to travel forecasting models. This gap only seems to grow wider as models advance in response to a growing number of applications and policy questions that models are being asked to address. While there are unknowns about the specific type of behavioral data that might be available from CAVs, it is clear that there is also a long list of possibilities for ways that CAV data can enhance the estimation, calibration, and validation of travel forecasting models.

A recommendation would be to continue to monitor the progress of connected and automated vehicle technologies. Partnerships should be made where possible to understand the evolving technologies and to further refine the expectations of what the data may be able to provide. The opportunities for research and / or pilot programs exist to help guide other agencies in the United States and around the world about the usage of these data in travel forecasting models.

REFERENCES

MDOT and CAR. Crowdsourcing Transportation Systems Data. 2015

NCHRP 20-24(98), Connected/Automated Vehicle Research Roadmap for AASHTO. 2015

Osman, O. and S. Ishak. Accounting for traffic density and market penetration in a newly developed connectivity robustness model for connected vehicles environments. 93rd Transportation Research Board Annual Meeting January 12-16, 2014

Transportation Systems Research Group, College of Engineering – Center for Environmental Research and Technology (CE-CERT), University of California, Riverside (UCR). Connected Vehicle Technology Challenge: Lane-Level Vehicle Positioning using DSRC as an Aiding Signal. 2008

U.S. DOT, FHWA. Mapping Technology Assessment for Connected Vehicle Highway Network Applications. Presented at CGSIC, Seattle, Washington. August 2012.

U.S. Department of Transportation ITS JPO. The Smart/Connected City and Its Implications for Connected Transportation. FHWA-JPO-14-148. October 14, 2014

APPENDIX A: MDOT STAKEHOLDER MEETING MINUTES

Meeting place: MDOT Lansing Office
Date: 6/10/2015
Time: 1:30 pm – 2:45 pm
Attendees:

Niles Annelin, MDOT
Susan Gorski, MDOT
Karen Faussett, MDOT
Tim Ryan, MDOT
Jesse Frankovich, MDOT
Qiang Hong, CAR
Joshua Cregger, CAR
Sarah Binkowski, PB
Scott Shogan, PB

1. The group discussed and commented on existing data sources for travel forecasting, including:
    - The census data is the principal source of socio-economic data.
    - REMI forecasts from University of Michigan are the basis for population, employment and household forecasts.
    - MDOT has developed their own employment database.
    - MDOT has completed commercial origin-destination surveys and is not relying on the old survey data used by SEMCOG.
    - MDOT is currently considering a statewide transit on-board survey (in part to feed some of the economic modeling being conducted), but to date the costs are simply too high and funding is trying to be identified.
    - The state is increasingly relying on third-party data sources (HERE, RITIS, etc.)
2. Current Data Gaps: the following were identified as gaps or challenges with data:
    - There is not a single source of data – many sources must be compared or fused in order to get a complete data picture
    - There is not enough speed data on lower functional classified roadways
    - Cost is not necessarily driving data collection decisions or sample sizes – MDOT feels comfortable that the samples collected are appropriate
    - MDOT is increasingly being asked to look at all travel modes as part of the models (particularly in small urban areas where MDOT develops/maintains the models), and the data sources do not support this well to date.

- Tourism and recreational travel characteristics are difficult to capture, as well as seasonal variation

3. Impact of CAV on forecasting: After a brief overview of CAV and the potential data sources from it, the following was discussed in terms of the potential for impacts to the forecasting process from new data sources:
    - At the statewide model level, CAV data would mostly support improved model validation, including productions/attractions and route choice, and not necessarily wholesale replacement of other sources, or major changes to modeling.
    - Current OD data does not include route, so CAV data could support better understanding of routing choices for validation.
    - The huge datasets would be overwhelming and would need third-party processing.
    - There is still an unknown with regards to the cost of purchasing this data, and whether it would have sufficient benefit to justify the cost.
    - When discussed as to whether CAV data would make MDOT consider transitioning to Activity-Based Modeling (ABM), the response was possibly, particularly to capture alternative modes for the smaller MPO models.
    - It was mentioned that the statewide model is pretty simple (24-hour period only, single mode, etc.), and that maybe that's all it needs to be – it's currently meeting MDOT's needs. CAV data is more appropriate in resolution for more detailed urban/operational modeling, but possibly too disaggregated for the statewide level.
4. Next Steps: Scott indicated that the intent is to gather information from stakeholders, supplement that with additional research, and develop a report by September. MDOT indicated that they would be interested in looking at CAV data to understand better how it could support them. The data collected from the Safety Pilot Model Deployment in Ann Arbor was identified as a possible source which could be coordinated with MDOT's ITS Program Office.

APPENDIX B: SEMCOG STAKEHOLDER MEETING MINUTES

Meeting place: PB Detroit Office
Date: 6/9/2015
Time: 11:30 am – 1:45 pm
Attendees:

Tom Bruff, SEMCOG
Liyang Feng, SEMCOG
Saima Masud, SEMCOG
Richard Wallace, CAR
Qiang Hong, CAR
Eric Dennis, CAR
Sarah Binkowski, PB
Scott Shogan, PB

1. Current SEMCOG data sources for travel forecasting
    - Traditionally, the HH survey, on-board transit survey, commercial vehicle survey and external survey are used as resources for SEMCOG model development. These surveys are done at various intervals in the model update cycle and they are very costly ($1M+ each).
    - Census data is the primary input for the socio-economic data development. The American Community Survey is used to develop zonal level demographic data along with UrbanSim's population synthesizer. In general, 48-hour classification counts are used for model validation.
    - SEMCOG also collects traffic counts conducted by local agencies, which amount to 3000-4000/year.
    - Travel time info is now taken from third-party sources (HERE, AirSage etc.), whereas SEMCOG used to conduct their own floating car runs for this. The data is used more to support Dynamic Traffic Assignment (DTA) and congestion management, and not as much for forecasting model validation.
    - Mature freight model is still years away. Commercial vehicle survey data is from 1996 – very dated. SEMCOG is looking for a more efficient approach to address the data issue.
    - Origin-Destination (OD) data is from sources such as AirSage and Streetlight
    - The survey for internal-external trips (from the SEMCOG model area) was conducted in 1995 – very dated and SEMCOG is looking for a better, more efficient approach to collect these data.

- SEMCOG has had challenges with employment data sources due to sensitivity of the data and complexity of employment types. Due to confidentiality of the current ES202 based employment data, SEMCOG is unable to share with consultants/third parties – looking for new data sources.

2. Current Data Gaps: the following were identified as gaps or challenges with data:
    - Looking for better ways to address non-home-based trips with current data sources
    - Activity Based Modeling (ABM) will do a better job of addressing non-home-based trips, but still needs a better stratification to feed the simulation.
    - Data cost drives modeling: average model update cycle costs millions. The model development cost is far less than the surveys. That cost limits the sample sizes that are possible.
3. Impact of CAV on forecasting: After a brief overview of CAV and the potential data sources from it, the following was discussed in terms of the potential for impacts to the forecasting process from new data sources:
    - CAV data is likely too disaggregated for a traditional 4-step model, because those models do not simulate individual vehicles or trip chains, In this context, it is likely to be a ground-truth source only.
    - CAV data would more likely have a bigger near-term impact on calibration of models, particularly at the DTA or microsimulation levels. They are not too useful to existing assignment methods.
    - The forecast itself is done by linking travel behavior to socio-economic data, and then projecting the socio-economic growth/changes into the future. Given this, the data has the potential to replace the household survey which is currently conducted only IF there was a way to link the vehicle/non-motorized data to personal information such that a connection can be made between travel behavior and socio-economic information.
    - Current simulation software does not support the CAV data derived travel behavior, more researches are needed. Meanwhile, the current simulation algorithms and computing/processing capability would need to be substantially improved in order to handle the simulation. .
    - CAV data would fit better in an ABM context, but even within current ABM modeling there is a limit to the number of household types you can model. CAV data would still need to be aggregated into a smaller number of household types until the computer power and algorithms are there to handle the large disaggregated data set.

- It would be difficult for SEMCOG to collect this data themselves or store/process raw data – they would be looking for a third-party to purchase processed data from.

4. Next Steps: Scott indicated that the intent is to gather information from stakeholders, supplement that with additional research, and develop a report by September. SEMCOG indicated that they would be interested in piloting use of CAV data to understand better how it could support them.
    - The data collected from the Safety Pilot Model Deployment in Ann Arbor was identified as a possible source for exploring a pilot opportunity. The one-day sample data from Safety Pilot Model Deployment is available on the USDOT Research Data Exchange website (https://www.its-rde.net/showds?dataEnvironmentNumber=10014).

APPENDIX C: LIST OF ABBREVIATIONS

ABM	Activity-based Model
ACS	American Community Survey
CAR	Center for Automotive Research
CAV	Connected and Automated Vehicle
DTA	Dynamic Traffic Assignment
DSRC	Dedicated Short-range Communications
GPS	Global Positioning System
MDOT	Michigan Department of Transportation
MPO	Metropolitan Planning Organization
NHB	Non-home Based
NHTS	National Household Survey
NHTSA	National Highway Traffic Safety Administration
OD	Origin-destination
OEMs	Original Equipment Manufacturers
PTR	Permanent Traffic Recorder
SEMCOG	Southeast Michigan Council of Governments
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WAVE	Wireless Access in a Vehicular Environment