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CENTENNIAL PAPERS

Standing Committee on Highway Traffic Monitoring (ABJ35)
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Highway Traffic Monitoring —Understanding Tomorrow's Problems to Better Serve the Public

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YESTERDAY

Establishment of the Highway Traffic Monitoring Committee (ABJ35)

Even before the advent of Intelligent Transportation Systems (ITS), the Highway Traffic Monitoring Committee (ABJ35) was identifying best practices, gaps, and research needs related to traffic monitoring programs. Initially established as a Weigh-in-Motion (WIM) Task Force (A2B51) in 1985, it transitioned to a standing committee in 1988 (A2B08) and was subsequently redesignated ABJ35 in 1994. Table 1 lists the chairs and co-chairs of the Committee since its inception as a Task Force. The Committee comprises an active group of 25 to 30 members (including three emeritus members) representing public transportation agencies, university professors and researchers, traffic monitoring equipment vendors, and consultants.

TABLE 1 Chairs and Co-chairs of the Highway Traffic Monitoring Committee

Name	Office	Years Served
Kent, Perry	Chair	Nov.18, 1988 – Jan. 31, 1995
Huft, David	Chair	Feb. 1, 1995 – Jan. 31, 2001
Gardner, Mark	Chair	Feb. 1, 2001 – Apr.14, 2007
Gillman, Ralph	Chair	Apr. 15, 2007 – May 31, 2009
Keen, Peter	Chair	Jun. 1, 2009 – Jul. 14, 2012
Keen, Peter	Co-chair	Jul. 15, 2012 – Apr. 14, 2015
Stolz, Elizabeth	Co-chair	Jul. 15, 2012 – Apr. 14, 2018
Regehr, Jonathan	Co-chair	Apr. 15, 2015 – Apr. 14, 2018
Regehr, Jonathan	Chair	Apr. 15, 2018 – Apr. 14, 2021

Mission and Purview of the Committee

The mission of the Highway Traffic Monitoring Committee is to provide resources, support, and guidance to enable, enhance, and advance the state of the practice of highway traffic monitoring and data collection technologies, methods, and management. Accordingly, the Committee is concerned with the research, monitoring, and reporting of roadway traffic data, such as counts, class, and weights of motorized and non-motorized transportation vehicles and pedestrians. The Committee also assists in the development of standards that support these functions.

The core of the Committee's purview involves all functions of traffic monitoring programs, most notably those administered by state and federal departments of transportation (DOTs). As customer data needs evolve, new technologies emerge, and collaborative opportunities arise, the Committee adapts its focus by establishing new subcommittees. The paragraphs below summarize the key functions of the subcommittees.

- The Archived Data User Service (ADUS) Subcommittee (ABJ35-1) was established in 2002 to coordinate TRB activities related to the archiving and management of highway traffic data collected via intelligent transportation systems (ITS) and other systems designed for traffic operations. As data archiving became a mainstream topic, the subcommittee ceased activities in 2013 and paper reviews were absorbed into several other TRB data committees.
- The WIM Subcommittee (ABJ35-2), the forerunner of the present Committee initiated by former Chair Ralph Gillman, was established to support research, development, and application of WIM technologies in the United States and internationally. This subcommittee fosters collaborative relationships with the International Society for Weigh-in-Motion and various pavement, bridge, and asset management committees within TRB.
- The Bicycle and Pedestrian Data Subcommittee (ABJ35-3) was formalized in July 2011 in response to a need for accessing, sharing, and integrating nation-wide bicycle and pedestrian travel information. This subcommittee, which has formal linkages with the Bicycle Transportation (ANF20), Pedestrian (ANF10), and Urban Transportation Data and Information Systems (ABJ30) Committees focuses on non-motorized travel data acquisition including volume counting, understanding traveler behavior, and capturing relevant supporting transportation data. Emphasis is also placed on activities that enable new technologies, collection methods, and data management techniques. The subcommittee has been extremely active since its inception, with the ultimate goal of becoming a recognized TRB Task Force.
- The Travel Time, Speed, and Reliability Joint Subcommittee (ABJ30-3) was formally established with the Urban Transportation Data and Information Systems Committee (ABJ30) in 2013, after existing as an informal paper review group for several years. This joint subcommittee is the principal collaborative mechanism linking the Committee with the Urban Transportation Data and Information Systems Committee.
- The Research Subcommittee (ABJ35-4) was formed in 2018 to assist in developing Research Needs Statements and other documents in support of the research topics identified in Research Circular E-C227 (see below).

Major Accomplishments of the Committee to Date

The Committee fosters research related to traffic monitoring by disseminating and publishing new research through TRB, developing sessions and workshops at the TRB annual meetings, identifying new research needs, and posting relevant documents on its website: https://sites.google.com/site/highwaytrafficmonitoring/home. Several major accomplishments are particularly notable:

- In 2017, the Committee realized it required more focused efforts to identify research needs, develop Research Needs Statements, and secure funding to perform key investigative programs. As a result, Research Circular E-C227—*Advancing Highway Traffic Monitoring Through Strategic Research* (*1*) was prepared and published later

that same year. In 2019, the Committee was recognized by the TRB community for this effort, earning an Honorable Mention for a Blue Ribbon Award in the category of *Leadership: Contributing to Improving the Management and Operation of TRB Committees*. The ideas in this document provided the catalyst to form a new Research Subcommittee (ABJ35-4).
- Due to our Committee's and others' efforts, non-motorized travel is now recognized as an important component of traffic monitoring. Through numerous collaborative efforts over the past decade, we assisted agencies in the development of non-motorized traffic monitoring programs. The 2014 publication of Research Circular E-C183—*Monitoring Bicyclists and Pedestrian Travel and Behavior*: *Current Research and Practice* (*2*) represents a landmark achievement.
- Committee members were instrumental in forming the biennial National Travel Monitoring Exposition and Conference (NaTMEC) and continue in critical support roles. NaTMEC provides travel monitoring professionals and transportation data users from around the world opportunities to share knowledge and good practices, exchange ideas, revisit fundamental concepts, learn new processes and procedures, and explore the latest advancements in policy, technology, and equipment.

Committee members offer their expertise in the development of seminal national and international guidance and standards in the traffic monitoring field. Key examples of these documents include the various editions of the Federal Highway Administration's *Traffic Monitoring Guide* (*3*), the *AASHTO Guidelines for Traffic Data Programs* (*4*), the Transportation Association of Canada's *Traffic Monitoring Practices Guide for Canadian Provinces and Municipalities* (*5*), *ASTM E1318: Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods* (*6*), *ASTM E2300: Specification for Highway Traffic Monitoring Devices* (*7*), *ASTM E2532: Standard Test Methods for Evaluating Performance of Highway Traffic Monitoring Devices* (*8*), and *ASTM E2561: Standard Practice for the Installation of Inductive Loop Detectors* (*9*).

TODAY

As part of the preparation for creating Transportation Research Circular E-C227 (*1*), the Highway Traffic Monitoring Committee surveyed the state of the practice, best practices, current issues, needs, and research gaps for each of the topics in the circular. This section summarizes the findings of Transportation Research Circulars E-C227 (*1*) and E-C183 (*2*).

Traffic Monitoring Program Management

State of the Practice

Traffic monitoring program management typically resides within the planning division or planning office of a state DOT or other regional transportation agency. Its responsibilities include oversight of data collection, processing, analysis, and reporting. The AASHTO *Guidelines for Traffic Data Programs* (*4*) includes guidance for all facets of traffic monitoring from data collection equipment selection to generation and submission of required reports.

Best Practices

A mix of unique and common approaches are used by states to manage their traffic monitoring programs. The unique approaches include:

1. Customized guides and manuals that explain the policies, organization structure, business processes, and technology tools (including traffic databases) that support and manage traffic monitoring programs.
2. Data business plans and self-assessment tools to improve management of traffic monitoring programs.
3. Traffic data programs that leverage operations and ITS data collection or local data collection. Examples include collecting both traffic data for the traffic monitoring staff and speed data for the ITS staff and collecting data from regional agencies around the state.
4. Emerging trends that include complete or partial privatization of traffic monitoring programs and coordination with asset management and ITS programs regarding maintenance of traffic monitoring program equipment.

Current Issues, Needs, and Research Gaps

State and municipal DOTs face challenges concerning traffic monitoring despite the increasing availability and use of private sector traffic data sources due to the following issues.

1. Ability to respond in a timely manner to changes in federal guidance or mandates (*3,10,11*) that may impose different data collection or reporting requirements.
2. Business practices deeply embedded in the *culture* of the agency (e.g., continued use of manual processes and “that’s the way it’s always been done” mindset).
3. Business area *silos* that inhibit sharing of traffic data and information across or between business units (e.g., ITS data and traffic monitoring data).
4. Agency structure that impacts traffic monitoring program management practices such as use of staff resources to maintain data collection field equipment and lack of coordination with ITS staff for maintenance of both ITS and continuous count station equipment.
5. Lack of specific traffic monitoring program data business plans (or updated traffic monitoring program manuals and handbooks).
6. Knowledge transfer and training challenges posed by retirements and integration of new staff.
7. Lack of formal protocols for sharing of traffic data between the state DOT and local government agencies.
8. Identification of the advantages and challenges to full or partial privatization of traffic monitoring programs.

Continuous Traffic Count Programs

State of the Practice

Continuous counting encompasses collecting vehicle volume, vehicle class, and vehicle weight information for the nation’s roadways continually with an often hourly or smaller time increment over a period of more than one week. Continuous counting motor vehicle traffic data are delivered to the Federal Highway Administration (FHWA) on a monthly basis (*4*). Traffic monitoring programs are conducted by in-house staff, contracted staff, or combinations of both. State-of-the-art programs deploy a variety of technologies such as radar, in-pavement loop detection, and video detection systems whose strengths and limitations are described in the references (*3*,*12–15*). Many DOTs dedicate a section of roadway for comparing the accuracies and types of data available from the different sensor technologies.

Best Practices

Best practices include deploying continuous counting equipment that identifies classification distributions and temporal traffic patterns by vehicle class, including bicycle and pedestrian. These guide the factoring process that converts short-duration counts into average annual daily traffic (AADT) estimates. Optimizing the location of the continuous count devices to produce the required factors at the desired level of accuracy is often a challenge of this technique.

Emerging trends incorporate visualization into data analysis procedures, for example as described in *Statistical Methods and Visualization* (*16*). Collecting traffic data once and using the data for many purposes and many times is a trend that many data collection agencies, including the FHWA, encourage. An example is traffic data collection programs that are an integral part of an asset management function (*17*).

Current Issues, Needs, and Research Gaps

Traffic monitoring program data quality requirements are not consistent among all interagency departments and prevent them from sharing traffic monitoring sites, equipment, and data. Gaps in knowledge and practice in many DOTs cause data integration challenges due to the use of different sensor technologies and differences in cultural and institutional coordination practices (*18–20*).

Specific needs are coordinating operations across the ITS and traffic monitoring divisions and integrating ITS data with traffic monitoring program data. Most issues with the ITS data result from the lack of complete data from ITS sites that prevents DOTs from utilizing this non-traditional permanent source. This motivated the FHWA to develop an innovative AADT calculation technique (*3*) that, unlike the AASHTO method, reduces bias and permits smaller than daily time increments in AADTs.

Short-Duration Traffic Count Programs

State of the Practice

Short-duration count programs provide accurate estimates of the volume, class, and weight of vehicles on the roadway network. These programs satisfy FHWA Highway Performance Monitoring System (HPMS) reporting requirements, supply information for individual projects, assist in developing lane closure policies, and classify the types of vehicles using the roadway. Short-duration counting is typically performed for one to seven days at any location and time throughout the year and can include hourly and sometimes 15-min or daily accumulations of data. Unlike continuous count programs, short-duration counts are significantly less expensive to conduct.

Short-duration count data are dependent on the type of sensor used. Data categories include number of axles, axle spacing, traffic volume, volume by vehicle class, speed, bumper-to-bumper length, gap, and headway (*21*). The data may either be aggregated over time or on a per-vehicle basis. The count data are collected with portable traffic recorders (PTRs) and automatic traffic recorders (ATRs) from road tubes, tape switches, piezo sensors, and a variety of non-intrusive sensors. To develop AADT estimates, many agencies multiply the average daily traffic (ADT) from a short-duration count using one or multiple adjustment factors.

Best Practices

Best practices include the use of non-intrusive sensors (i.e., those located above or to the side of the roadway, to obtain short-duration counts). Equipment software typically provides tools that allow users to create graphs and traffic reports, calibrate equipment and traffic parameters, edit and analyze data, create automated tests to verify analysis results for specified conditions, export and email results in commonly-used formats, customize formats for time and measurement units, and enable automated data processing and quality assurance/quality control (QA/QC) procedures. Some equipment can be accessed remotely over the Internet allowing monitoring and transferring of data in real-time.

Current Issues, Needs, and Research Gaps

Current issues, needs, and research gaps include the following:

- Lack of specificity and definable characteristics for assigning short-duration counts to groups of seasonal adjustment factors (SAF) may triple the prediction error (*3,22,23*).
- Concerns of states regarding Highway Safety Improvement Program (HSIP) requirements to collect and utilize a subset of Model Inventory of Roadway Elements (MIRE) fundamental data elements (FDE) for all public roadways.
- Absence of agreements between many state agencies and local agencies to coordinate data collection activities that would eliminate duplication of efforts and the inability to share resources.
- Need for data collection personnel to annotate the collected data to indicate the underlying reasons for any data abnormalities.
- Data processing and quality challenges arising from dissimilar software in the various data acquisition equipment, and equipment quality variations from vendor to vendor.
- Inaccurate traffic counts obtained during periods of high traffic volume or congestion (*24*).
- Inability to properly secure road tubes on the pavement surface.
- Equipment malfunctions, communication issues, and other technical failures affecting the amount and quality of data collected.
- Safety of staff that install or maintain short-duration traffic equipment.

Weigh-in-Motion

State of the Practice

WIM sensor technologies include in-pavement strain or hydraulic pressure gauges, in-pavement piezoelectric sensors, and sensors that monitor the response of bridge structural members. In-pavement sensors are the most widely-used technology in the United States. Sensor costs align with data quality measures such as accuracy, repeatability, and reliability. Recognized WIM standards are the ASTM E1318-09 Standard (*6*), European COST 323 Standard (2002) (*25*), and NMi International WIM Standard (2016) (*26*).

Best Practices

Best practices in WIM data collection by state transportation agencies include:

- Site selection and installation that conforms to the ASTM E1318-09 Standard (*6*).
- WIM sensors with low sensitivity to changes in temperature or pavement stiffness.
- Continuous collection of per-vehicle formatted (PVF) data (*3*).

- Automated data quality checks that enable fast identification of data quality issues and seasonal variations in truck weights and routine preventive maintenance.
- Ground-truth validation and field calibration using heavy trucks of known weight (*27*,*28*) and the procedures contained in (*6*) and (*27*).
- Enhancements such as vehicle images linked to measurement data, license plate and vehicle registration readers, and gathering of inductive loop vehicle signatures that re-identify vehicles to obtain travel time and origin-destination data.
- Addition of WIM data to web-based traffic data visualization and analysis tools (*29*), data sharing between multiple users, and utilization of WIM data for the Mechanistic-Empirical Pavement Design Guide (MEPDG) (*30–35*).
- Incorporation of the WIM smoothness index, LTPP method for WIM validation and calibration, and use of WIM operation management tools (*36–38*, *39–41*).

Current Issues, Needs, and Research Gaps

Current concerns with implementation of WIM technology include:

- High equipment costs leading to less than desirable maintenance and calibration practices that cause data quality degradation.
- Sensitivity of some WIM sensor technologies to variations in temperature and to pavement structural response under load.
- Difficulties in sharing WIM data collected by different vendors' systems because of variations in raw data formats.

Additional national research issues are improving the accuracy of multiple-sensor WIM systems; WIM sensor calibration using connected vehicle V2I communications or WIM controller-to-vehicle communications; and integrating WIM data to improve decision-making and transportation network management, mobility, and safety.

Managing Large Traffic Datasets

State of the Practice

Temporally- and spatially-organized traffic data stored in large databases originate from continuous and short-duration counts; detector stations; volume, speed, classification, weight, and per vehicle records; and metadata. State-of-the-art programs deploy systems to collect and transmit counts from the devices, perform initial QC checks to determine completeness of the data and advanced QC checks to confirm the data fall within acceptable ranges, and establish methods to store and report the traffic data.

Best Practices

Best practices include collection of speed data, nonmotorized vehicle and pedestrian data, PVF data, crowd sourced data, real-time data, and use of the revised AADT calculation method that accommodates data collected over a variety of time increments (*3*). Less expensive data storage, improved processing abilities, addition of QC methods, and the reduced cost of data transmission make the collection of PVF data cost effective. Data stored in relational databases can cross-reference records in different tables and create relationships between the tables. Geo-located traffic count, classification, and weight data that appear in large datasets can be quality analyzed and integrated with other datasets for safety, roadway management, and operations uses.

Current Issues, Needs, and Research Gaps

Structured and unstructured data are available from traffic monitoring stations. Examples of structured data are those that conform to existing national, state, or local procedures. Often local counts and those conducted to support individualized research or another customized need may not contain the structured aspects that support utilization in a large database. Although these data cannot be fully utilized for annualization applications, they can serve as a quality control dataset for the larger annualization datasets.

Documentation of data collection methods, key fields, database relationships, and data availability are lacking. Combining traffic monitoring datasets, which are created for different purposes (e.g., research, project studies) but which also can serve traffic monitoring needs, has the potential to quadruple motorized traffic volume, broaden and enhance coverage of nonmotorized traffic volume, and require big data management skills and resources to adequately exploit the datasets (*42*).

Performance Measures

State of the Practice

Performance measures, coupled with well-defined and well-communicated targets, provide transparency and clarity to the resource allocation decision-making process (*43*). Example performance measures for traffic data collection and analysis include number of days past January 1 needed to produce the AADT factor, number of days past end of month it takes for regions or districts to submit permanent traffic counts, number of good sites per day (i.e., those that provide volume and class), and number of WIM station lanes working per day (*44*). Illustrative performance measures that satisfy the Moving Ahead for Progress in the 21st Century Act (MAP-21) mobility requirements are percent of person-miles traveled on interstate highways that are reliable, percent of person-miles traveled on the non-interstate National Highway System (NHS) that are reliable, truck travel-time reliability index, annual hours of peak hour excessive delay per capita, percent of non-single occupancy vehicle (SOV) travel, and total emissions reduction.

Best Practices

Two key best practices in the area of performance measures are: (1) agency use of traffic data to measure system functioning including reporting, visualization, and decision making related to efficient planning and operation of the system and (2) their application to traffic data programs to ensure data quality, coverage, timeliness, and accuracy (*3*). Many states employ dashboards to display their measures. Exemplary mobility performance measures programs around the county are noted in references (*45–48*).

FHWA's Transportation Performance Management (TPM) website provides a comprehensive resource for rule-making, requirements, and state noteworthy practices for implementing a TPM program; data collection and management; target setting; project prioritization and decision-making; reporting; collaboration; and external links to several state and city TPM dashboards (*49–51*).

Current Issues, Needs, and Research Gaps

States are challenged with providing traffic data and vehicle miles traveled (VMT) on all roads. Many states have well-developed traffic monitoring programs, but they often only apply to state-owned facilities and rarely incorporate nonmotorized data. Some states use estimates of VMT for the non-state-owned facilities, while others develop affiliations and programs with partner agencies (*52*).

Combining traffic volume with speed data from private data vendors or from the FHWA through the National Performance Management Research Data Set (NPMRDS) is often challenging due to the different highway segments that exist in each type of data. A related need concerns applying probe data (such as INRIX and HERE) to estimate traffic volumes.

Tools to integrate, analyze, and visualize traffic volume data with other parameters such as speed, incidents, and weather are expensive and are not always supported for ad hoc performance management at the public agency level.

Other gaps are lack of knowledge sharing across states in how to apply performance measures to manage traffic data systems, resolving segmentation and conflation issues, developing tools to support congestion management and forecasting, developing capabilities for non-motorized data collection and estimation (such as bicycle and pedestrian), developing vehicle occupancy measures and estimates, and determining the most critical variables for forecasting mobility, and passenger versus freight and truck versus commodity volumes.

Pavement Engineering Applications

State of the Practice

The state of practice in pavement engineering relies on empirically derived relationships between traffic summary statistics and pavement performance (for example, road roughness) monitored over time with respect to traffic and environmental loads, site conditions, material properties, and construction practices. These studies frequently describe the traffic state with a single summary parameter such as equivalent single axle load (ESAL), average annual daily truck traffic (AADTT), cumulative truck volume, or total load (*53*). ESAL and AADTT are the most common.

Best Practices

Pavement engineering is undergoing a paradigm shift from empirical to mechanistic-empirical design methods. The mechanistic-empirical method requires extensive use of traffic data instead of simply one traffic summary parameter, namely ESAL. Best practice applies the MEPDG and AASHTOWare Pavement ME Design software that utilize a set of input parameters in a specific format (*34,35,54*).

Traffic loads, presented as axle load spectra (axle load distributions), support modeling of pavement response resulting from axle load magnitudes, number of axle load applications over a specified period of time, and load configuration (i.e., the number of axles in each axle load group) (*35*). Jointed rigid pavements require the relative positions of axle loads on the pavement in addition to the axle load spectrum.

Best practices incorporate the relative pavement performance impact factor (RPPIF) and the annual total truck load (ATL) traffic-loading summary statistics. The RPPIF (*35*) statistic is computed similarly to ESAL, but instead of the load equivalency factors (LEF) based on the data from the AASHO Road Test, it utilizes *W* factors determined through MEPDG analysis and globally-calibrated distress prediction models and software (*55*).

Current Issues, Needs, and Research Gaps
Research is needed to (1) develop sensors that accurately capture the detailed traffic loading history and location and size of the loading area (tire footprint and load distribution) to enable mechanistic pavement analysis, design, and management methods and tool creation, (2) improve WIM tools that assist in monitoring and maintaining the desired accuracy and removal of bias from heavy axle load measurements, and (3) explore the feasibility of inexpensive portable WIM data collection equipment in combination with other data sources to estimate traffic loads for pavement design (*31*).

In addition, techniques are needed to improve data collection (1) for pavement design to accurately estimate site-specific axle loading from the limited number of WIM sites maintained by state highway agencies, (2) concerning freight carried by trucks on specific highways, and (3) from connected vehicles (e.g., on-board truck sensors capable of transmitting truck or axle weight data).

Data Quality and Equipment Calibration

State of the Practice
QA/QC methods appear throughout continuous and short-duration count programs (*4*). The TMG (*3*) contains best practices for field device calibration using ground truth data from manual counts performed by human observers, video recording followed by post processing counts by human observers, and comparisons with counts from a gold standard counter.

Best Practices
State-of-the-art programs utilize automated systems to support data reliability and accuracy and provide near real-time data. Many agencies have established methods for database structures that include computerized data collection and storage by lane or travel direction, email of daily downloads, and reporting of completeness, quality issues, and status of each day’s data.

Several state DOTs collect data for all vehicle types at WIM sites and over 10 collect per vehicle weight data. Some agencies pay for data that are both complete and of good quality instead of having in-house staff perform such work. Many agencies provide data online, enabling public review and feedback that leads to improved information availability and decision making. Geo-locating data and visualizing them on maps along with other geographic information system (GIS) layered data allows agencies to improve their asset management system (*17*,*18*).

Volume data from HPMS, the Travel Monitoring Analysis System (TMAS), and the National Household Travel Survey (NHTS) afford opportunities to verify data quality and calibration and help ensure that reported values represent the vehicle mix actually traveling on the roadway network.

Current Issues, Needs, and Research Gaps
Gaps in knowledge and practice are manifested as technology issues, cultural differences, and lack of coordination procedures. They hinder some interagency departments from sharing traffic monitoring sites, installation procedures, equipment, and data. Documentation of data acquisition and recording methods, data entry fields, database relationships, and data availability are often lacking. Manual data analysis becomes more complex as data from monitoring sites operated by different agencies are combined because inconsistent QA/QC methods may be employed by the various agencies.

Recommended research includes the following:

1. Specification of a tolerance for the acceptable variability in the collected data accompanied by a confidence interval or level.
2. Improving methods to automate site calibration, for example, by incorporating roadside readers that collect transponder data, GPS and other global navigation satellite system location information, and Bluetooth data to verify classification site accuracy.
3. Identification of data to fill in missing counts and the associated types of metadata.

Integrating Traffic Counts with Connected Vehicle Data

State of the Practice

At this juncture, the state of the practice of the Connected Vehicle Program is in its infancy in the United States. Three connected vehicle pilot deployment projects funded by the USDOT in New York City; Tampa, Florida; and Wyoming are uncovering what barriers remain and how to address them, documenting lessons learned, and serving as a template to assist other early connected vehicle technology deployments. It is unclear at this time whether these programs will be able to provide traffic count data (*56*).

The AASHTO Connected Vehicle Signal Phase and Timing (SPaT) Deployment Challenge, led by the V2I Deployment Coalition with support from other organizations and consortia, is spearheading an effort to deploy a dedicated short-range communications (DSRC) infrastructure with SPaT broadcasts in at least one corridor or network (approximately 20 signalized intersections) in each of the 50 states by January 2020. As of January 2019, the SPaT Challenge had commitments from 26 states with 216 signals operational and 2,121 signals planned (*57*). Again, it is unclear at this time whether these programs will be able to provide traffic count data.

Best Practices

Best practices are difficult to ascertain since the Connected Vehicle Program is immature. Deployments are limited to projects funded by the USDOT and state agencies, or are in part sponsored by automobile manufacturers and consortia. Other examples include two projects in Las Vegas. The first alerts the driver of how fast to drive to continue to get a green signal or their anticipated wait time at the red signal (*58*). The second, a collaborative multi-agency, multi-company, and university project, equips Las Vegas city-owned cars with V2I communications that provides alerts or warnings for bus stops, high-risk areas, speeding, and traffic stopped-ahead incidents (*59*). Other testing programs in the State of Michigan are exploring V2V, V2I, bicycle, and pedestrian interactions (*60,61*). AT&T, Ford, Nokia, and Qualcomm conducted trials in San Diego to demonstrate the potential of cellular-V2X technologies to improve automotive safety, automated driving, and traffic efficiency (*62*). This communications technology may have implications for transmission of data that can assist in traffic counts.

Current Issues, Needs, and Research Gaps

The issues below potentially have the greatest impact on the ability of counting programs to exploit connected vehicle data.

- How can counting programs efficiently use connected vehicle data? What potential does it unlock? What skill set changes are required?

- Will the types of connected vehicle data and messages already planned meet the needs of traffic counting programs?
- What interface or standard should be used for counting programs and traffic operations to exploit connected vehicle data?
- How will an agency's lack of knowledge concerning connected vehicle data, messages, and ability to collect, store, and apply them affect traffic count data collection?
- What is the self-sustaining business model or funding source that will pay for the infrastructure portion of the connected vehicle system and for acquisition of data that could be used to satisfy traffic count mandates?
- What security procedures are needed in applications that allow local and state traffic management personnel to access the data (*63*)?
- What is the impact on privacy of Big Data analytics that extract value from connected vehicle data?
- What are the impacts of the National Highway Traffic Safety Administration's decision to quietly back away from a proposed mandate for all new cars and light trucks to be equipped with V2V communication technology beginning in 2021 (*64*)?
- What are the relations among onboard computing speed, computing bandwidth, and channel congestion?

Travel Time, Speed, and Reliability Data

State of the Practice

Travel time, speed, and reliability data are commonly used by transportation agencies and researchers to quantify the quality of flow on the transportation network. Data sources for speed, travel time, and reliability analysis are typically probe-based systems, point detector systems, or combinations of both. Four reliability measures are recommended by FHWA: 90th or 95th percentile travel time, buffer index (BI), planning time index (PTI), and frequency that congestion exceeds some expected threshold (*65*). Additional measures of reliability are also included in the MAP-21 rulemaking (*11*).

Best Practices

Over the last decade, a number of private sector companies have been selling travel time data derived from a combination of probe data and agency-provided data. Research is ongoing to explore options to estimate volume data from the probe data, which has historically been a limitation of private sector probe data streams (*66*). The evolving methods involve the fusion of historic estimates, nearby real-time counts, and adjustments based on models relating real-time speed estimates with those from other sources. Travel time reliability and congestion research is developing models and algorithms to evaluate network-wide performance using simulation tools to measure freeway performance in terms of travel time reliability and to locate areas of congestion.

Current Issues, Needs, and Research Gaps

While MAP-21 rulemaking provides needed national level consistency in congestion and reliability reporting, current variations in overall assessment methods are exacerbated by the following:

- Lack of standard definitions of travel time reliability and metrics for roadway segments and networks.
- Deficiency of comprehensive high-quality data across all facilities.
- Accessibility of probe data sets.
- Need for Big Data analytics tools**.**
- Absence of data fusion to reduce the uncertainty from individual sources and to enhance information quality (*67*).

Bicycle and Pedestrian Travel Monitoring

State of the Practice

The collection and use of bicycle and pedestrian data on a broad scale is an emerging field within traffic monitoring and not yet institutionalized or nationally mandated as it is for motor vehicle data. Many fundamentals contributing to the state of the practice build from what is currently known and practiced for motor vehicle traffic monitoring, particularly as it relates to continuous counts. Sampling practices for short duration cyclical programs are not consistent and, for many agencies, the basic bicycle or pedestrian network facility data are not well-inventoried, further complicating one's understanding of the population of road or path segments from which to sample. Many agencies collecting nonmotorized count data do so for special project or research study needs and may still use manual methods to acquire the data. However, as nonmotorized traffic monitoring programs are becoming more prevalent, agencies are investing in automated equipment, technologies, and software to collect, store, verify, analyze, and report these data. Some agencies manage databases created in-house, while others use data management software supplied by count equipment manufacturers. FHWA's TMAS added functionality to archive and report bicycle and pedestrian data, but few agencies have done so yet. Furthermore, there is currently no reporting requirement for state DOTs to do so. Research is underway to explore different methods to develop adjustment factors to obtain AADT estimates for short duration sites. However, this is complicated by a lack of data at short duration locations and the use of different strategies for grouping continuous counters with similar travel patterns across varying geographic and climatic scales.

Best Practices

Short duration counts should be collected for a minimum of seven continuous days in months where higher bicycle or pedestrian travel is expected. After initial installation of continuous counting equipment, at least 12 hours per day per site for one weekday and one weekend day are needed to conduct a robust validation process to ensure equipment functionality and correct calibration. Data should be monitored daily or weekly to identify problems and troubleshoot maintenance promptly to minimize lost data due to vandalism, insect activity, or mechanical problems. The small scale, higher variability, and sensitivity to weather or other factors associated with bicycle and pedestrian volume data make quality checking more challenging (*68*).

Current Issues, Needs, and Research Gaps

Growth in the need and use of bicycle and pedestrian volume data will continue to push for improving all aspects of traffic monitoring related to these data types. While some issues parallel those identified for motorized traffic monitoring, others are unique to bicycle and pedestrian data needs and challenges. Specific needs and research gaps include:

- Improved detection technology to differentiate pedestrians in crowds and bicyclists in shared lane situations.
- Data sharing and integration with traditional traffic monitoring programs and transportation partners and sharing with non-traditional partners (including data security aspects related to privacy).
- Creating consistent standards for data structures and formats to support compilation of data collected through different technologies, vendor equipment, and agencies.
- Developing best practices for incorporating nonmotorized data into performance measures, program evaluations, and funding decisions.
- Using data to understand equity considerations and transportation-disadvantaged populations.
- Exploring the value of non-traditional data sources, such as bike share vendors and crowdsourced travel monitoring data (Strava, Cycletracks).
- Mainstreaming nonmotorized volume data into regular local and state DOT business practices by incorporation into safety, maintenance, and operations analyses.

TOMORROW

Summary of Trends and Emerging Issues

The Committee has identified numerous trends and emerging issues and is actively engaged in promoting and pursuing research on the following topics:

- Privatization of traffic monitoring programs and coordination with asset management and ITS programs to maintain traffic monitoring equipment.
- Incorporation of visualization into data analysis procedures.
- Collection of traffic data once for multiple-purpose use.
- Increasing the pace of incorporating new WIM sensor technologies, expanding use of WIM data in new applications, and improving WIM program management and operations.
- Increasing the pace of incorporating new pedestrian and bicycle sensor technologies, particularly as other mobility devices emerge (e.g., e-scooters and hoverboards), expanding use of nonmotorized data in new applications (e.g., health measures, route choice, and near-miss metrics), and improving nonmotorized program management and operations.
- Utilization of structured and unstructured data for quality control purposes.
- Incorporation of the relative pavement performance impact factor (RPPIF) and the annual total truck load (ATL) traffic-loading summary statistics to monitor pavement distress.
- Determining how counting programs can efficiently use connected vehicle data, while recognizing that bicyclists and pedestrians may not be “connected”.
- Considering how travel behaviors, wayfinding, data collection, and storage capabilities may be impacted through changes in information technology, social media, and advanced mobile devices

- Fusion of historic estimates, nearby real-time counts, and adjustments based on models relating real-time speed estimates with those from other volume sources.
- Need for Big Data analytics tools.

Future Priorities, Initiatives, and Challenges

To address the trends and issues listed above, the Committee developed the following priority research areas (*1*,*2*):

1. Novel methods and technologies for characterizing truck flow: axle loads, commodities, on-board weight, portable WIM.
2. Best practices for managing traffic monitoring program equipment and related assets.
3. Methods to visualize traffic data from traffic signal systems.
4. Accuracy requirements of traffic counts for different applications.
5. Advanced messaging requirements for connected vehicles to meet traffic monitoring and operations needs.
6. Big Data analytics for extracting value from connected vehicle data without compromising privacy.
7. Validation of methods to assign short-duration counts to factor groups.
8. Detection and validation of abnormalities and unusual trends observed through short-duration counts.
9. Using probe data to estimate traffic volume.
10. Standard definitions for travel time concepts that address inconsistencies, ambiguities, errors, failure states, and performance measures.
11. Developing methods to integrate data streams for intermodal systems analyses.

In addition to pursuing the foregoing research topics, the Committee has identified several priority initiatives in keeping with its mission:

- Increase the numbers of research and synthesis proposals submitted for NCHRP and FHWA funding.
- Advance the Joint Bicycle and Pedestrian Data Subcommittee to a full committee.
- Provide federal regulatory highway traffic monitoring guidance and support.
- Enhance guidance and support materials with a web-enabled repository of highway monitoring information.
- Coordinate with the connected vehicle community to ensure that traffic count data are included in transmitted messages or data.
- Strengthen relationship with relevant committees in AASHTO to ensure that the Committee remains abreast of their efforts related to data collection and traffic monitoring.
- Maintain partnership with NaTMEC through attendance and support of program development.

As traffic counting programs continue to evolve, keeping abreast of changes in traffic monitoring hardware and software technologies and the private sector sources of data will become more critical. Methods of collecting, distributing, and displaying data will continue to advance, providing traffic data users with never before imagined data analytics and necessitating the need for new performance measures and the means to gather, store and analyze Big Data.

Policy developments are difficult to predict. However, given its history and the Committee’s ability to adapt and change to meet shifting priorities and policies, the current

Committee is confident that it will continue to play a critical role in the traffic monitoring field well into the future.

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