

NCHRP Project 08-145

***Using Cooperative Automated Transportation Data for Freeway
Operational Strategies***

IMPLEMENTATION OF RESEARCH FINDINGS AND PRODUCTS

Meenakshy Vasudevan, and Karl Wunderlich

Noblis, Washington, DC

Kaan Ozbay, and Jingqin Gao

C2SMART University Transportation Center, Department of Civil and Urban Engineering, Tandon
School of Engineering, New York University, Brooklyn, NY

The National Cooperative Highway Research Program (NCHRP) is sponsored by the individual state departments of transportation of the American Association of State Highway and Transportation Officials. NCHRP is administered by the Transportation Research Board (TRB), part of the National Academies of Sciences, Engineering, and Medicine, under a cooperative agreement with the Federal Highway Administration (FHWA). Any opinions and conclusions expressed or implied in resulting research products are those of the individuals and organizations who performed the research and are not necessarily those of TRB; the National Academies of Sciences, Engineering, and Medicine; the FHWA; or NCHRP sponsors.

Permission to use any unoriginal materials has been
obtained from all copyright holders as needed.

Introduction

Cooperative Automated Transportation (CAT) envisions all stakeholders and elements of the transportation system working together to improve safety, mobility, equity, and operations efficiency through interdependent vehicle, infrastructure, and systems automation enabled by connectivity and information exchange (AASHTO 2020). Cooperative Automated Transportation allows for the generation and sharing of electronic messages and when these messages are collected, data elements extracted and leveraged by agencies' transportation management system (TMS), operational strategies can be enhanced to better manage and improve traffic flow and safety. CAT data refers to data elements contained in electronic messages generated and wirelessly exchanged among connected and automated vehicles (CAVs), mobile devices, and connected infrastructure, and utilized by the TMS to facilitate this concept. In the context of freeway operation, CAT data includes data extracted from Basic Safety Messages (BSM), MAP messages, Traveler Information Messages (TIM), Road Safety Messages (RSM), Connected (Mobile) Device Messages, as well as certain private sector or third-party data.

Cooperative Automated Transportation enables CAVs, mobile devices, and the connected infrastructure to exchange messages even on facilities and areas where traditional forms of vehicle and road-user detection (e.g., in-pavement sensors/loop detectors) are limited (e.g., on rural highways, arterials, surface streets) or disrupted (e.g., due to construction, faulty detectors) (National Academies of Sciences, Engineering, and Medicine 2022). A mature CAT has the potential to improve a TMS operator's situational awareness, significantly increase the geographic area their systems monitor and support, improve the timeliness of information used for decision-making, enhance the precision of control parameters utilized in operational strategies, or enable new forms of highly precise and individualized speed recommendations for connected and automated vehicles. The resulting impact may reduce reliance on deployments of dense infrastructure sensors, a more resilient transportation system, and better situational awareness for drivers, fleet managers, and system managers and operators.

Certain operational strategies, such as variable speed limits, that may be used to manage and operate traffic along a freeway, could collect and use electronic messages generated by CAVs along a corridor. Data elements extracted from these electronic messages could be used by the agencies' TMS to estimate system-wide or route-based measures (e.g., route or corridor travel times or delays). These strategies might be more tolerant of gaps in the messages introduced due to reduced market penetration of CAVs or connected infrastructure. Other strategies, such as ramp metering, could use data extracted from messages generated by CAVs in a specific area to estimate localized measures (e.g., queues at a ramp meter). Unless there is sufficient market penetration, the number of messages that may be generated in the area of interest might be limited. This may reduce the ability of the TMS collecting these electronic messages to accurately estimate these measures. Hence, in the near-term, effectiveness and deployment readiness of an operational strategy that uses only data extracted from CAT generated electronic messages might be limited by low market penetration rates of CAVs and non-uniform availability of these messages. Even if the market penetration increases, CAT data may still be sparse due to where these CAVs may be operating or distributed in the ecosystem.

Inconsistencies in positioning accuracy of electronic messages pose significant challenges, especially for strategies requiring lane-level precision. Incorporating CAT data into an existing TMS may bring new vulnerabilities from cyber-attacks. Identifying tradeoffs between cybersecurity, the value of the data, and the transmission speed remains a gap. Significant efforts might be needed to upgrade existing devices and TMS to process electronic messages generated by CAT.

Despite the gaps and challenges identified above, CAT data could be used to enhance the capabilities of existing strategies and performance measurement applications. Agencies may be encouraged to implement CAT for enhancing freeway operations when a clear approach to

realizing tangible value beyond traditional approaches that do not leverage CAT data sources is available to them.

To help address these challenges, the National Cooperative Highway Research Program (NCHRP) initiated this research project, specifically to assess use cases where freeway operational strategies could be improved through the transmission of data between a TMS and the larger CAT (either directly or through a third party). This assessment could (1) spur development of enhanced and new operational strategies and (2) help agencies justify gaining access to additional CAT data. This research project accomplished the following:

- **Developed use cases for ten strategies selected by the NCHRP Project Panel as the ones with the most relevance to freeway operations and with the highest potential for improvement with CAT data.** The ten strategies were Queue Warning*, Ramp Metering, Dynamic Route Guidance*, Speed Harmonization and Lane Control for One Lane, Traffic Incident Management*, Integrated Decision Support and Demand Management*, Speed Harmonization for Entire Roadway (one direction on freeway), Performance Monitoring*, Variable Pricing for One Lane, and Variable Pricing for Entire Roadway. For the purpose of this project, an operational strategy is defined as a strategy that can be used by an operator to directly manage and control freeway systems. Based on this definition, it should be noted that not all of the aforementioned strategies may be classified as a freeway “operational” strategy. However, these strategies considered by the panel reflect areas most likely to benefit from the use of CAT data as well as dissemination of information via connected infrastructure to CAVs, and mobile devices. Strategies that do not fall under this definition of an “operational strategy” are indicated with an asterisk.
- **Developed, tested, and assessed the effectiveness of two approaches for ramp metering that utilized CAT data in a simulation environment.** The study was conducted using a simulated model for the I-210 corridor. Two approaches utilizing CAT data, namely queue-informed and incident-aware ramp metering algorithms, were developed. The queue-informed algorithm employed more accurate on-ramp queue estimations derived from CAT data to regulate metering rates, while the incident-aware algorithm integrated feedforward control into feedback ramp metering to address distant bottlenecks and offers more precise traffic information, including traffic flow, travel time, and density, surrounding incidents.

The findings of this study indicate that significant benefit may accrue from the tailored integration of CAT data into freeway operational strategies. This project focused on ramp metering as a particularly promising area for the incorporation of CAT data into operational practices. The findings of this project highlight the *promise* of CAT to improve ramp metering. However, other operational strategies are also likely to benefit from the utilization of CAT data.

This report provides a high-level set of considerations for an agency interested in moving forward towards such enhanced freeway operational strategies and practices. However, because of project resource and scope limitations, there is significant work yet to be conducted to provide detailed guidance for deployers. This includes a more formal and structured methodology for integrating CAT data into their TMS to manage and operate freeways as well as less formal guidance regarding entry points and low-lift processes for screening and scoping potential new projects before committing to detailed systems engineering and eventual deployment. Part of this effort reflects the summary assessment recommended as a part of the deployment concept development. However, even more work and guidance are needed regarding the cost-effective integration of analytical tools like simulation models to refine initial designs and embed performance monitoring and continuous improvement processes within any deployed system. A potential first step in this process is documented here; however, this represents only an initial foray into a broader set of activities that has the ultimate goal of creating practical and detailed guidance for prospective CAT deployers.

Purpose

The purpose of this memorandum is to promote the use of the ramp metering strategies that utilized CAT data as well as the adaptation of use cases of freeway strategies developed as part of this research to move transportation agencies to action and put the research into practice. This memorandum identifies the audience and market for the products, lays out the roadmap for its successful implementation (including possible barriers to success and actions to overcome them), and provides the criteria for judging progress and the consequences of implementation. The memorandum presents a set of activities that will:

- Introduce the products to key transportation audiences and generate awareness among transportation agencies considering the use of Cooperative Automated Transportation to augment or replace traditional infrastructure-based detection for freeway operations and management.
- Encourage transportation agencies to adapt the products to their specific needs and operational environment.

Research Products

The research products include: (i) operational concepts/use cases for ten freeway strategies that utilized CAT data; (ii) baseline and enhanced ramp metering strategies that utilized CAT data and related source code, and software documentation; (iii) source code and supporting documentation for queue estimation using machine learning for use in the queue-informed ramp metering strategies; and (iv) source code and supporting documentation for enhanced BSM Emulator. The source code and corresponding documentation will be posted on GitHub under the MIT License, which is a permissive free software license. In addition, we have included guidance and tips for tailoring and fine-tuning the algorithms for specific conditions, thus enabling other researchers to adapt the algorithms as needed.

Target Audience and Skills

The target audience for the products include: (1) transportation agencies who are either current or prospective deployers of CAT, including connected and automated vehicle (CAV) technology; (2) research/academic community members who are actively engaged in algorithm development using BSM and other CAV data for freeway operations; and (3) other practitioners and researchers involved in traffic analysis, Transportation Management Systems, and transportation operations.

An agency interested in using the research products will need a multi-disciplinary team, comprising transportation engineers, systems engineers, software programmers, and data analysts. At a minimum, adaptation and implementation of the products requires understanding of BSM data, some software development skills, and some proficiency in data management tools. Systems engineering skills will be needed to make the necessary changes to the TMS, and deploy the technology required by the TMS to collect and use BSMs. If the TMS has to send electronic messages back to a CAV, specialized skills for deploying CAV technology will be needed. In addition, traffic operations engineers with experience in managing, operating, and revising operational strategies will be needed to apply or update the algorithms. Systems engineering skills will also be needed to adapt and tailor the use cases for their specific freeway corridors and related needs.

For tailoring the machine learning model for queue estimation for use in ramp metering, more advanced data skill is needed. Although the analyst does not need to be an expert data scientist, he or she should have a basic understanding of machine learning to grasp the steps for refining the parameters and re-training the model.

Impediments to Successful Implementation and Risk Mitigation

There are several barriers to successful implementation, including:

- **Audience awareness/engagement with project products:** To mitigate this barrier the research team made sure that (1) the ten freeway strategies for which use cases were developed and the freeway operational strategy (ramp metering) that was enhanced and tested were selected by a panel of experts and practitioners (NCHRP Project Panel), who identified the strategies as having the most relevance to freeway operations and with the highest potential for improvement with CAT data; and (2) the source code for the enhanced strategies is well-documented, scalable, and runs error-free. The NCHRP Project Panel provided feedback on materials as these were developed, thus helping identify issues early in the process. The project team briefed the panel thrice during the project, on the various products, thus gathering feedback incrementally. The products developed are modular, so an agency can easily tailor the products to meet their specific needs.
- **Technical complexity in tailoring project products:** Lack of guidance can make the adaptation by researchers and practitioners time-consuming and complex, and even cause them to abandon implementation. To mitigate this barrier, we included guidance for refining the parameters under various conditions. Additional guidance will be needed for agencies to plan and design the next generation of their TMS to incorporate CAT technologies and capabilities needed to collect messages, and extract, and use data from the messages generated by CAT.
- **Required audience expertise to utilize products:** Expertise can be an obstacle for implementation by agencies. In the previous section, we have identified the type of skills required for adapting and applying the products.
- **Motivating organizational leadership within audience organizations:** This can be mitigated by demonstrating the value proposition of the research products through outreach activities (e.g., presentations, webinars, demonstrations), especially by practitioners (other agencies) and researchers who have successfully implemented the research products. We will document potential outreach activities in the next section.
- **Obtaining funding for product implementation:** This is a common barrier to the application of any new process, technology, or technique. Agencies may want to consider other options, including the Connected Vehicle Pooled Fund Study (PFS), and Traffic Management Center (TMC) PFS. There may also be dedicated funding from agencies such as FHWA (thus negating the need for state and local agencies for carving out funding). The project team has proposed establishing a cohort for collaborative open-source adaptation and implementation thus reducing the resources required by agencies, not part of the cohort, for adapting the algorithms, in the next section.

Implementation Approach and Implementation Champions

The implementation approach consists of two options for taking the research product to the practitioner:

1. Option 1 is a no cost, low level of effort to introduce the project and products to key transportation agencies, immediately following completion.
2. Option 2 requires NCHRP 20-44 funds to advance product implementation through a webinar (expansion of the first option), and a pilot cohort activity to adapt the use cases as well as the ramp metering strategies with agencies planning for Cooperative Automated Transportation.

Option 1 is to introduce the products to key transportation audiences, immediately following project completion. The NCHRP 08-145 Project panel members would be excellent candidates for reaching out to the target audiences with information about the use cases and ramp metering strategies that utilized CAT data. To reach the target audience for the products, the project team recommends sharing the documents with the TMC PFS, Connected Vehicle PFS, National Operations Center of Excellence (NOCoE), Freeway Operations TRB Committee (ACP20), and similar organizations.

The Final project presentation could be used to market the products at the various committee and organization meetings. In addition, the project team recommends that TRB publishes the final report, publishes an article in the TR News, and highlights the project in a TRB newsletter. These low-cost activities could help keep interest in the project outcomes and in the forefront of agencies planning for CAT.

Option 2 involves a two-phased approach that would require additional funds from NCHRP 20-44 to advance product implementation. The first phase includes a webinar (expansion of Option 1) and a 2-page factsheet on the products and the benefits of using the products. The second phase involves putting the research into practice. The project team proposes establishing a pilot cohort for deployers of ramp metering using CAT data. Depending on NCHRP 20-44 funding resources, and expressed interest, the project team, with input from the NCHRP 08-145 Project panel, could select agencies to be part of the pilot cohort. The selected agencies should have participated in the Phase 1 webinar to be better prepared for the activity. In the envisioned activity, the project team would provide guidance to the cohort agencies to use or adapt the relevant ramp metering strategies for their specific needs. These activities could include working with the agencies to: (i) identify the relevant strategy based on their specific needs; (ii) download and set up software, including for queue estimation using machine learning if queue-informed ramp metering is selected; (iii) determine the geographic and temporal scope for implementation; (iv) process BSM data for use; (v) refine parameters and tailor algorithms, including re-train machine learning based queue estimation algorithms; and (vi) evaluate the benefits of ramp metering strategies using CAT data against the baseline strategies using traditional infrastructure data. The cohort agencies would need to agree that any code that is modified is made open source and openly shared with their peers. Doing so will serve to promote collaboration and sharing within the cohort and the broader CAT community.

More details of the two-phased approach are provided in the Required Resources section.

Implementation Champions. Potential institutions that might take leadership in deploying the research product include Federal Highway Administration (FHWA), American Association of State Highway and Transportation Officials (AASHTO) and State and local Department of Transportation (DOT), including the three CV Pilot Sites (New York City DOT; Wyoming DOT; and Tampa Hillsborough Expressway Authority [THEA]).

Required Resources

The project team recommends that NCHRP 20-44 funds be requested to execute this Implementation Plan as a follow-on effort to the initial NCHRP 08-145 project. As described above, the implementation identifies the target audience and recommended activities immediately following the project completion. Those activities are low level of effort to promote and market the project and product.

The second option of the Implementation Plan is composed of two phases. The first phase is a natural extension of the completed project research. Phase 2 is a natural extension of the Phase 1 outreach. Discussion and feedback from webinar participants will help agencies and consultants better understand the processes for tailoring the ramp metering strategies to address specific needs and encourage the use of the products. Piloting the use and tailoring of the strategies with

guidance from the project team will serve as a training and learning tool that could assist other agencies. The project team having conducted the research project is well positioned to conduct both phases effectively and efficiently.

Phase 1 could consist of one webinar (2-3 hours). The intent of the webinar would be to delve deeper into the process of how the strategies were developed and evaluated, thus priming the participants to begin thinking about their local needs and unique situation. The webinar will present the process for downloading and setting up the software; processing BSM data for use; refining parameters and tailoring algorithms, including re-train machine learning based queue estimation algorithms; and evaluating the benefits. In addition, the webinar will discuss what may be needed by agencies to collect and process BSMs, and issues to consider with collecting and incorporating BSMs and other associated data, and the software into their system. The webinar will be free and open to anyone. In addition, the webinar slides, and recording will be made available for others to access and use. As part of Phase 1, a 2-page fact sheet describing the products will also be prepared. The Phase 1 rough order magnitude cost estimate for one webinar, including recording, and a 2-page factsheet is approximately \$15,000. The cost estimate includes webinar promotion, factsheet development, webinar preparation, presentation, and recording.

Phase 2 consists of the launch of one pilot cohort with support from the project team. The intent of the pilot cohort activity is to guide the cohort agencies through the tailoring process. The entire process would span several months with short periods of our team working with the agencies to walk through the process, followed by longer periods of time for the agencies to execute the work with review and guidance from the project team. The support will be virtual. The Phase 2 rough order magnitude cost estimate for labor to support up to two agencies is approximately \$40,000. The cost estimate includes labor for setting up the cohort, initial meeting with the cohort agencies, consulting on: (i) identifying the relevant strategies based on their specific needs; (ii) downloading and setting up software; (iii) determining the geographic and temporal scope for implementation; (iv) processing BSM data for use; (v) refining parameters and tailoring algorithms, including re-train machine learning based queue estimation algorithms; and (vi) evaluating the benefits.

Criteria for Success

As much as it is important to put the research into practice, it is also important to measure the progress and success for implementation. Criteria that should be considered for judging the progress and consequences of implementation include:

- Number of product downloads once files are posted by NCHRP (e.g., Final Report, code).
- Number of agencies or organizations that have used the products or tailored them for a specific deployment.
- Number of TRB papers that cited the products.
- Number of promotional support activities and announcements.
- Number of participants in Phase 1 outreach activities.
- Feedback from Phase 1 participants on the research products.
- Number of agencies expressing interest in becoming part of the Phase 2 cohort.
- Feedback and lessons learned at the completion of the cohort activity from the cohort agencies.