KYTC Evaluation of Automated Traffic Signal Performance Measures

Background

In September of 2017 the Kentucky Transportation Cabinet (KYTC) applied for Accelerating Innovation Deployment (AID) funding to install equipment that would enable implementation of Automated Traffic Signal Performance Measures (ATSPM) on two corridors. In its application, the Cabinet provided several justifications for the proposed project. Importantly, the funds would give the agency its first opportunity to experiment with ATSPMs. Perhaps more critically, KYTC staff had exhausted the phasing options available with outdated signal technologies. Due to the amount of fieldwork and staff resources involved, the Cabinet could update signal timings only every 4 – 5 years. Because of the long intervals between updates, KYTC could not formulate and implement adaptive and dynamic phasing strategies which reflect and are responsive to real-time variations in traffic observed throughout the year — an issue salient in urban areas. AID funding would let agency personnel identify corridor types where ATSPMs and sophisticated signal and phasing technology confer the most benefits to traffic flow. The Cabinet proposed installing advanced signal controllers, new traffic signal controller cabinets, and equipment that supports vehicle-to infrastructure (V2I) communications on two high-volume routes in Bowling Green and Richmond (Table 1 and Figure 1).

Table 1 AID Project Routes

Location	Roadway	Route	# of Signalized Intersections
Bowling Green	US 231	• WN 9007 to US 31W	23
Richmond	Richmond Bypass	• KY 876 – Goggins Lane intersection to US 25 – Keeneland Drive intersection	25

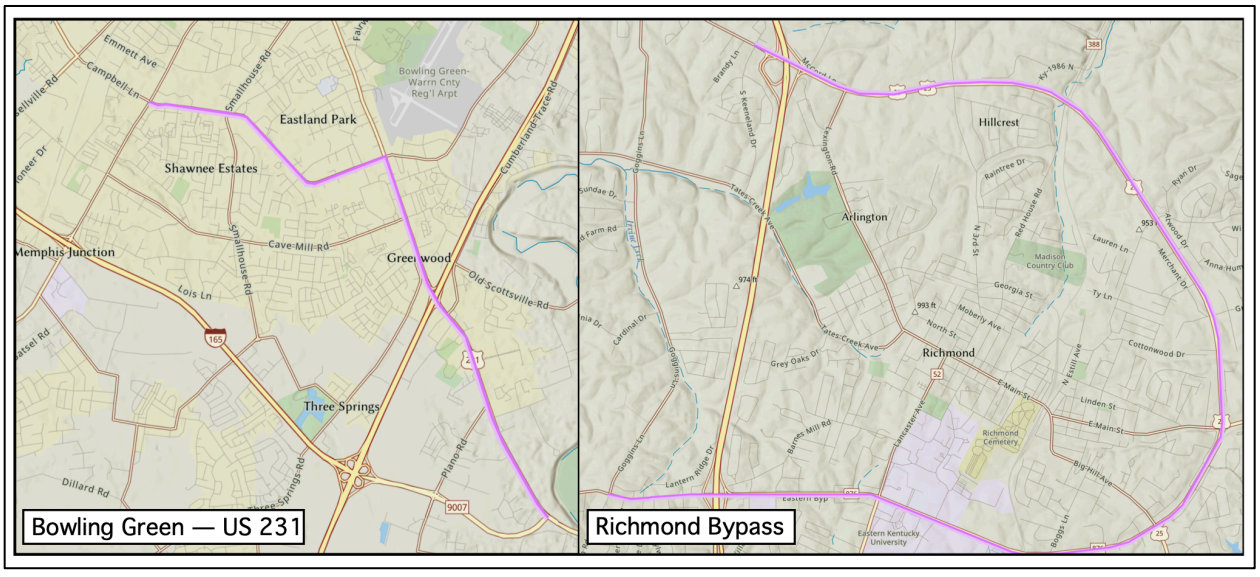

Figure 1 AID Project Routes (Routes Highlighted Magenta)

Piloting ATSPMs, Cabinet officials hoped, would improve traffic safety and travel time reliability, strengthen mobility, and give agency staff the chance to leverage high-resolution data sets collected from the continuous monitoring of intersections. Thinking more broadly, KYTC personnel viewed the project as a helpful starting point to document the experience, benefits, and challenges of adopting ATSPMs on corridors whose traffic characteristics vary widely; allow for validation of new connected vehicle (CV) technologies; and accelerate implementation of ATSPMs on corridors

where they could be most effective. The Cabinet's application listed performance measures the agency intended to collect data on following once new equipment had been installed. These included:

- User complaints before and after installation
- Proactive detections and reactive modifications
- Installation, operation, and maintenance costs
- Travel time information and congestion performance
- Crash data and safety performance

After the Federal Highway Administration (FHWA) notified KYTC of the award in March 2019, Cabinet staff began to investigate the experiences of other state departments of transportation (DOTs) with ATSPMs, CV, and advanced signal technologies.

As the project unfolded over the next 3+ years, KYTC encountered a number of challenges related to the project letting, equipment installation, supply chain disruptions, getting software operational, equipment testing, and the rapidly shifting terrain of federal rulemaking to reduce the CV reliant 5.9 GHz spectrum for DSRC radio technology from 75 MHz to 30 MHz, eliminate channels for use in the lower band, requiring that DSRC radio technology use channel 180 of the upper 30 MHz, reserve remaining upper 30 MHz for future C-V2X technology, and write rules for either sharing the remaining spectrum or phase out DSRC radio technology.

While KYTC used DSRC radios on this project, the agency encountered resistance from equipment manufacturers and vendors that began shifting away from DSRC technologies due to the uncertainty over whether the dedicated spectrum would be available for this use into the future. To date, no rulemaking has been published to phase out DSRC Radio technology. However, waivers granted by the Federal Communications Commission (FCC) in April 2023 allowing several automakers, technology firms, and state DOTs to use LTE cellular vehicle-to-everything (C-V2X) for safety-related applications in the remaining 5.9 GHz band appear to confirm that DSRC is unlikely to be a major factor in CV applications moving forward.

Despite these hurdles, KYTC installed new signal controllers and radar detection to implement ATSPMs and installed roadside units on the two project corridors. Signal phase and timing messages from the RSUs were confirmed by testing conducted by portable onboard units (OBUs).

Although few vehicles have the onboard equipment needed to receive messages broadcast by DSRC radios (and therefore measure their performance), installing radar detection and advanced signal controllers at the project intersections has and will benefit Cabinet-managed infrastructure. These systems are improving vehicle detection, intersection monitoring, and strengthening signal phasing and timing (SPaT) and traffic management.

Nonetheless, the Cabinet documented lessons learned throughout the project that will prove valuable on future efforts related to ATPSMs, CV technology, and the installation and maintenance of new signal controllers. The rest of this report is structured as a chronological narrative that summarizes major events and key milestones, with lessons learned at each turning point stated concisely. In adopting this structure, the goal is to articulate important considerations that DOTs and transportation agencies should be mindful of as they work through distinct phases of projects which aim to improve signal performance, driver safety, and traffic management.

Chronological Project Narrative

April – May 2019 Information Gathering

After the grant was awarded and KYTC staff prepared to develop contract documents and advertise the project, they interviewed and conducted separate ASTPM and/or CV peer exchanges with state DOTs officials in Utah, Florida (Tampa Hillsborough Expressway Authority CV Pilot and Florida DOT) Georgia, Virginia, North Carolina, and Arizona (Maricopa County DOT).

Alongside interviews with outside subject-matter experts, KYTC staff collected and analyzed travel time data for each corridor to establish their baseline performance. Additionally, they visited all project intersections to inventory signal controllers, other equipment, and potential challenges a contractor may encounter (e.g., conduit availability from signal controller cabinet to signal pole). This process revealed all intersections only had 170 controllers installed and that KYTC would need to install 2070 controllers to support deployment of both ATSPM and CV applications.

Recommendations/Lessons Learned

- Agencies that lack experience installing advanced signal controllers and roadside units (RSUs), processing real-time ATSPMs, or procuring CV-related services benefit from discussing upcoming projects with personnel at external agencies. Knowledge from these agencies provides valuable insights that can be used to avoid pitfalls often encountered during initial deployments of CV/ITS applications, especially with respect to equipment installation, contracting, and partnering with private firms. These conversations cannot proactively neutralize all potential challenges an agency may confront, but documenting the hard-earned knowledge of experienced stakeholders can help DOTs draw up a road map for ATSPM and CV application deployment and brainstorm resolutions to potential risks and contingencies.
- Having a clear understanding of baseline performance is critical for identifying corridor segments hampered by congestion or safety issues. This information can be used to draw before-and-after comparisons that will shed light on what improvements in corridor performance are directly attributable to ATSPM and CV applications.
- Inventorying equipment lets agency staff determine what equipment needs to be procured and helps avoid equipment-related omissions in contract documents.

June 2019 – December 2019 Multiple Project Advertisements and Contract Award

After putting together contract documents throughout June, KYTC held the first pre-bid meeting in July. The meeting was sparsely attended, with only two contractors and one integrator present. With the first attempt at a letting, the Cabinet separated the Bowling Green (US-231) and Richmond (KY 876) work into separate projects. At the August letting, KYTC received a bid for only one project. The bid exceeded the entire project budget, compelling the Cabinet to reject the bid. Returning to the drawing board, the Cabinet combined the Bowling Green and Richmond work into a single project. This strategy proved successful, and the project was awarded in December.

Appendix A contains contract documents used to advertise the project.

Recommendations/Lessons Learned

- Initially splitting the Bowling Green and Richmond work into separate projects may have contributed to the lack of interest from prospective bidders. KYTC staff did not anticipate this problem. In hindsight, the Cabinet would have benefitted from engaging more in-depth with other DOTs on issues related to project advertisement and assembling procurement documents so that interest and competition among bidders is maximized.

- To expedite work, KYTC advertised the project as a construction contract. While this decision offered the quickest way to move the project forward given the agency's procurement limitations, it complicated project delivery and diminished the quality of project work. The lead contractor lacked project management experience and at times struggled with coordinating activities and communications among all stakeholders and subcontractors. Were the Cabinet to advertise a similar project in the future, it would use a professional services contract so that an integrator would be the project lead and the equipment installer a secondary contractor. One option would be to award separate contracts for the integrator and installer. Placing the integrator in the lead role could have streamlined efforts to get software operational.

  Another option is to begin small. Deploying new methods and technology for the first time can benefit from a phased approach that includes bench testing of all hardware and software to work through learning curves associated with open-source software tools as well as data mapping and security compatibility within unique agency IT environments. Once bench testing is complete, agencies can install systems at a limited number of locations before corridor-wide deployment.

  DOTs confront different procurement regulations and KYTC's experience may not translate to other contexts. Nonetheless, agencies should carefully consider the best methods for contracting ITS- and CV-related projects and determining what type of firm (e.g., integrator, installer) should take a leading role.

January 2020 – July 2020 Project Initiation, COVID Work Stoppage, and Equipment Installation

KYTC held a preconstruction meeting in January. In February, the Cabinet approved equipment shop drawings and met with the US Department of Transportation on RSU 4.0 and 4.1 GPS-related specifications, which is what RSU/OBUs receive the time from. In March, contractors began to install radar detection (Wavetronix) at project intersections. The agency also installed a serial cabinet in Bowling Green, but work slowed due to another project in the area requiring four signals to be rebuilt.

The onset of the COVID-19 pandemic toward the end of March undercut progress, particularly on the KYTC side of operations due to uncertain and changing work arrangements. COVID-19–induced disruptions left an imprint on the remainder of the project. However, by April installation of 2070 controllers was underway, and more Wavetronix units were installed in Richmond and then Bowling Green. Installation of the first four DSRC units occurred in July, while gba Systems Integrators field technicians established survey control points for each intersection to set up lane geofences in the FHWA MAP tool. Supply chain disruptions delayed the delivery of DSRC units, which pushed installations back to August (in Richmond) and September (Bowling Green).

Recommendations/Lessons Learned

- Few people could foresee the emergence of a global pandemic. Transportation equipment manufacturers had to negotiate production slowdowns when they could no longer quickly source the materials required to build goods. This highlights the importance of not depending entirely on just-in-time production techniques which delay the acquisition of needed materials until the last possible moment.
- KYTC and other agencies can benefit from thinking about the circumstances under which they should require contractors and subcontractors to obtain project materials as early in the project delivery process as possible. It is unrealistic to assume risks capable of bringing project work to a halt will always materialize, but risk-planning exercises should be more attentive to worst-case scenarios and their potential impacts. If nothing else, this may help pinpoint inefficiencies that would hinder project delivery even under ideal conditions.

August 2020 – October 2020 Software Installation and Testing

As installation of 2070 controllers wound down, attention turned to integrating hardware and software so controllers could transmit signal performance data to KYTC. This entailed gba System Integrators installing MAXVIEW updates, MAXTIME cv, and map data on the controllers in Bowling Green and Richmond as well as linking maps and signal phasing for SPaT data. In September, the Cabinet's Office of Information Technology (OIT) staff began to install Utah DOT's open-source ATSPM software on agency servers to communicate with traffic signals.

Over the next year OIT personnel spent a great deal of time working with the Utah DOT so KYTC could get its software operational on Cabinet servers. A Utah DOT staffer spent a lot of time helping OIT staff try to configure the software in a way that would circumvent KYTC's firewalls. Hardware and software requirements OIT was bound by placed the Cabinet in a difficult situation and stymied efforts to get the software working. The COVID-19 pandemic also proved vexing as it forced engineers and data specialists to figure out how to do everything remotely, including back-end software configuration. One major sticking point was the KYTC could not remotely network into US Department of Transportation Servers. Eventually DSRC radios were able to communicate information, but they did not generate performance data.

In September 2021, after failing to succeed with the Utah DOT's open-source software, the project team members opted for the limited ATSPM solution offered in MAXVIEW cv so they could evaluate its performance (more details provided below).

Recommendations/Lessons Learned

- Freeware (i.e., open-source software) is not free. While this point may seem obvious, agencies thinking about ATSPMs and CV applications need to approach software-related decision making with great care and not gloss over complications and costs that may emerge trying to get systems up and running. The intuitive appeal of open-source software is that it does not cost anything up front, freeing up resources for use elsewhere. But this argument elides the negative externalities that could materialize if implementation encounters roadblocks. For example, despite many agencies finding success with the Utah DOT's open-source ATSPM software, KYTC simply could not get it to work with the agency's IT infrastructure. Not only did KYTC incur resource drain due to an uncooperative blend of software and hardware, very generous Utah DOT staff spent a considerable amount of time providing assistance and troubleshooting.

  Agencies can avoid problems introduced by incompatible hardware and software by assessing, during planning or early in project development, whether existing IT infrastructure can accommodate proposed hardware and software solutions. Subject-matter experts from the agency, systems integrator, and installer must participate in these assessments to ensure that all stakeholders (a) are on the same page and understand what is possible given the agency's IT constraints and (b) can begin to formulate plans if necessary to work around constraints. Identifying challenges early on reduces the likelihood a project team will confront insurmountable obstacles that will require an overhaul in project delivery strategies, call for numerous change orders, demand additional procurement of materials/labor, or result in some combination of the three.

November 2020 – April 2021 Consequences of the FCC DSRC Ruling

In November, the FCC announced new rules for portions of the 5.9 GHz band (5.850 – 5.925 GHz), opening up a portion of the spectrum for unlicensed uses, including Wi-Fi and automotive safety applications. The 5.895 – 5.925 band was to be set aside for automotive safety applications that leverage cellular vehicle-to-everything (C-V2X)

technologies. The new rule designates C-V2X as the standard for all safety-related transportation and vehicle communications pending new rules to develop technology specifications and band interference testing. The FCC justified this move by observing automakers had not leveraged DSRC for automotive safety applications and that the mid-band spectrum remained mostly unused.

The FCC's plan to modernize the 5.9 GHz band had several practical implications for KYTC's project. Perhaps most importantly, channel 178 was no longer an option for CV applications, forcing the use of channel 180. This translated into a significant amount of rework, and in March the project team bench tested RSUs after modifying the channel to 180. Staff from the Georgia DOT assisted with troubleshooting to get the RSUs operational. In April, KYTC learned that while the radios were easily modified to channel 180, MAXTIME cv would require updated code to handle the switch to channel 180 — the software was hard coded for channel 178. Code modifications took 12 months to complete and were not finished until March 2022.

Recommendations/Lessons Learned

- Like pandemics, it is difficult to predict when federal rule changes may appear. Nonetheless, some lessons may be drawn from this episode. Project funding arrived at a transitional moment. Faced with the dilemma of adopting a proven though underutilized technology (DSRC), waiting for C-V2X stability testing and subsequent rules, or waiting for widespread 5G (still many years out in much of Kentucky), the Cabinet opted for DSRC. This was a reasonable choice given the knowledge KYTC staff had at the time.

  As project work commenced, it started to become clear — even prior to the FCC rule change (and subsequent granting of waivers for C-V2X applications in May 2023 — that a portion of the automotive industry was drifting toward LTE C-V2X for safety-imminent CV applications. Several industry stakeholders confirmed this. Q-Free (the developer of MAXVIEW cv) expressed its view that DSRC is on the way out and that the future lies with C-V2X. The company had little interest in spending money to develop new code for a few states to make its software compatible with radios operating on channel 180.

May 2021 – December 2021 Field Testing, Equipment Malfunctions, and Software Updates

Field testing began in June after OBUs were delivered in May. While OBUs confirmed the transmission of SPaT data, the InteliLight/Q-Free SmartData application display proved unstable and could not verify whether the SPaT message status aligned with the actual status of signal heads. Nor could it receive messages at distances between 1 m and 300 m, a requirement of the RSU 4.1 specifications. Field testing proceeded throughout the summer and fall, with KYTC formally deciding to abandon use of the Utah DOT's ATSPM software in September (as noted above).

Several equipment-related issues arose during this period. One DSRC radio was hit by lighting and had to be replaced, while another malfunctioned for initially unspecified reasons. Onsite investigations revealed a manufacturing defect in the radios that led to water ingress around the antennas. As water infiltrated, antennas corroded. To resolve this issue, and prevent it from arising again, the project team installed new antennas with weatherproofing tape.

In November, the US Department of Transportation updated its MAP generation tools, including adding TIM Creator and message validation tools. After a construction project impacted the Bowling Green corridor, maps and phasing were updated for five intersections.

Recommendations/Lessons Learned

- Issues related to the Utah DOT's open-source ATSPM software were discussed above and not rehashed here. However, one point worth mentioning is that it is important for agencies to not get trapped by the sunk cost

fallacy and exhibit a willingness to alter plans once it becomes clear a particular solution is not working out. Deciding to change course is difficult, especially after committing significant time and resources, but often this is the best and only way to accelerate project delivery. The threshold at which change becomes necessary will vary among agencies, however, early in project development, project teams should discuss procedures for deciding when to make these decisions and the methods that should be used to justify them (e.g., cost-benefit analysis, qualitative analysis (e.g., gathering the opinions of subject-matter experts)).

- Equipment-related problems may have been avoided had the project team more thoroughly investigated DSRC radio quality and performance before approving shop drawings and purchasing them. Before approving and purchasing radios, the project team should have evaluated a unit in person and conducted bench testing to verify their capacity to broadcast on a given channel was consistent with manufacturer claims.

January 2022 – June 2022 Continued Testing and Equipment Updates

In early spring, the project team continued updating DSRC radios to channel 180 and eventually shifted all licensed RSUs to channel 180 as mandated by the FCC. In March, recoding of MAXTIME cv was finalized after a year of work. In April, an OBU arrived from the US Department of Transportation (CAV Services) the project team used to conduct field tests of equipment and determine whether SPaT, MAP, and TIM messages could be validated.

July 2022 – October 2022 Validation Testing and Final Acceptance

In July, the FCC authorized KYTC to operate in the upper band of the 5.9 GHz spectrum. Before field testing began, the project team conducted bench testing to verify equipment received from the US Department of Transportation was operational (see list below).

Cabinet staff evaluated the performance of the advanced signal controllers and RSUs during field testing at all 49 project intersections in Bowling Green and Richmond. The goal of this testing was to validate the bi-directionality of SPaT, MAP, and TIM messages.

The following equipment was used to carry out field validation:

- Renesas OBU, Antenna, and GPS + TP Link Wi-Fi router
- Android Tablet from project OBU loaded with Kapsch V2X Insight app
- MH Corbin Nitestar DMI, to spot verify distance points for reception of SPaT and MAP messages
- Q-Free OBU for Basic Safety Messages (BSM) – Limited validation
- A laptop to configure equipment and run Multi Channel Test Tool software for alternate verification of data

One challenge field testers confronted using the Renesas OBU is that the Kapsch V2X Insight app setting must be set to channel 180. Occasionally, the unit reset — sometimes without warning — to channel 172. On this channel, SPaT and MAP messages only travel approximately 100 feet. Ensuring that the Renesas OBU remained on channel 172 allowed validation to proceed. Field testers used several methods to verify that messages were sent and viewable in the Kapsch V2X Insight app (Table 2).

Table 2 Summary of Verification Methods

Message Type	Validation Method
SPaT	• Compared application display to visible signal head display.
MAP	• Compared intersection layouts on the Kapsch V2X Insight application display to actual layouts.

TIM	• Verified randomly loaded messages with the application display when TIMs were in range.
BSM	• Limited verification of BSMs and main map status of MAXTIME cv firmware. This required enabling a setting in MAXTIME cv on several controllers in Richmond.

Field validation confirmed the advanced signal controllers, RSUs, and the OBU functioned as expected. Tables 3 and 4 summarize results. Staff from gba Systems Integrators helped with validation by correcting skewed, incorrect, and missing MAP files, after which information for all 49 intersections could be viewed on the Kapsch V2X Insight app. The distances at which SPaT, MAP, and TIM data were received ranged from less than 900 feet to over 3,500 feet Intersection geometry and line of sight affected the distance at which the OBU/Kapsch V2X Insight app received and displayed data for a downstream intersection, with early intersection visibility increasing the data range. Once RSUs came within range, data updated in real time at a rate greater than once per second.

Equipment issues were apparent at two intersections, both in Bowling Green. The first was at the US-231 – Campbells Lane/Lovers Lane intersection, where field testers observed a shorter range when approaching it in the northbound direction. From the other three directions, no issues with data range were noted. Second, a RSU radio located at the US-231 – McIntosh intersection was not working properly. Local Cabinet personnel replaced this radio with one from KYTC inventory.

Final field testing and acceptance occurred in October.

Recommendations/Lessons Learned

- Field testers recommended that KYTC upload and save to a server all active MAXTIME cv databases. While the databases would require changes for the BSM configuration, they contain all of the function MAP configuration files. These files are generated on the FHWA web tool, and there is an upper file size limit for installation in a controller's database. Files for some locations had to be manipulated to display properly in Kapsch V2X Insight app due to latitude/longitude errors in Bing Maps.

Conclusions and Key Takeaways

Despite successful validation testing, KYTC has not been able to generate the amount of performance data it had intended to. Hurdles (e.g., uncooperative hardware – software interfaces, evolving 5.9 GHz rules, equipment failures) had to be overcome at practically every step of project delivery and resulted in a cascading series of frustrations and delays.

Beyond problems with equipment and software installation, KYTC is apprehensive about the future maintenance of advanced signal controllers. Just two ATSPM systems are operational in Kentucky, and few signal technicians have the expertise or training required to keep the 2070 controllers needed to support CV applications in good working order. Signal technicians approaching retirement are disinclined to learn the minutiae of the new controllers. And with the Cabinet facing workforce recruitment and retention challenges — similar to state DOTs across the country — expanding deployments of advanced signal controllers and CV applications is going to likely hinge on the old fashioned human resources problem of whether enough qualified agency staff are available to operate and maintain these technologies. This problem lacks a simple or straightforward solution. Agencies must be proactive in their efforts to build a growing and resilient workforce that is ready to handle the demands to technologically challenging roles.

The six bullet points below summarize key lessons learned from the project (see the narratives above for detailed discussions). While the project did not unfold precisely as KYTC had envisioned, agency staffers came away with new experiences and valuable knowledge that can be applied on future CV/ITS projects.

- Interview experienced state DOT personnel and subject-matter experts before embarking on a complex CV/ ITS projects.
- Collect and analyze baseline performance data on project corridors to accurately quantify how CV applications influence traffic management and roadway safety.
- Select the contracting mechanism best suited to CV/ITS projects. This reduces the likelihood that sub-optimal project management and poor communication among team members will affect project delivery.
- Brainstorm risks that could reduce equipment availability and/or undermine supply chain resiliency. Develop plans early in project development to avoid or mitigate the effects of these contingencies.
- Federal rulemaking and burgeoning industry trends are powerful forces that can dramatically reshape the CV/ ITS space on short notice. Paying close attention to these forces and the changes they bring about helps DOTs adopt an agile, flexible posture and negotiate both expected and unexpected changes.
- Freeware is not free. Good software solutions often take the form of freeware, but agencies need to understand their hidden costs (e.g., the amount of time staff spend configuring software and hardware) and dedicate time during planning and project development to determine if freeware solutions are the best fit for their existing IT infrastructure. If a software solution appears unlikely to work out, agency staff should feel empowered to switch course before too much time or money is spent.

Table 3 Field Validation Results for US-231 (Bowling Green)

Signal Location	Intersection ID	MAC Address	Landmark	SPaT	MAP	TIM	BSM	Notes	900' (to West)	900' (to East)
US-231@Natcher Parkway	10967	04:F5:F4:00:29:71	Highway	X	X	X		900' + NB, 3400' SB, Test TIM in this controller in app @ 1360'	Mansion with fountain	House with pillars
US-231@Plano Rd	51031	04:F5:F4:00:28:55	Peachtree Place	X	X			2400' NB	Goodwill	Simply Mulch & More
US-231@Post Office - Cassie Way	60518	04:F5:F4:00:29:69	Shell, Post Office	X	X			2400' SB, Corrected MAP offset - 7/20/22	Farmer's National Bank	O'Reilly's
US-231@Cypresswood Lane	3188	04:F5:F4:00:2A:3F	Creative Interiors	X	X				Ely Drugs	South Central Bank
US-231@Cherry Farms	11397	04:F5:F4:00:28:22	I65 Liquors	X	X				Quality Inn	Car Mart
US-231@KY-2158 (Cumberland Trace)	17310	04:F5:F4:00:29:70	Shell	X	X			1350' NB, 1200' SB	65 NB on ramp	Zaxby's
US-231@I-65	23475	04:F5:F4:00:28:51	I65 Ramp	X	X				Chuck's Wine & Spirits	Hardee's
US-231@Three Springs - Bale Blvd	37327	04:F5:F4:00:29:6E	White Castle	X	X				Chipotle	Outback Steakhouse
US-231@Pascoe Way	44506	04:F5:F4:00:28:5B	Shoe Carnival	X	X				Fazoli's	Speedway
US-231@Arbys - Kmart	48353	00:20:A6:FF:B3:8B	Arby's - Kmart	X	X				Starbucks	McDonald's
US-231@Shive Lane - Cave Mill	52199	00:20:A6:FE:E1:50	Walgreens	X	X				Long Horn Steakhouse	Big Lots
US-231@Bryant Way	59379	04:F5:F4:00:28:44	Greenwood Mall	X	X	X		Test TIM here: 1710' NB, 1500' SB	Pedego Way	Walgreens
US-231@Campbell Ln - Lovers Lane	8204	00:20:A6:FF:B1:FD	Toyota, Honda	X	X			Shorter approach distance heading NB, then other 3 directions	U-Haul	Urgent Care
US-231@Gary Farms - Home Depot	5427	00:20:A6:FF:B3:7F	German Bank, Home Depot	X	X				Big B Cleaners	Best Buy
US-231@Walton Way	1888	00:20:A6:FF:E9:4F	Barnes and Noble	X	X				McDonald's	Chick-Fil-A
US-231@American Way - Lowes	65401	04:F5:F4:00:2A:2E	Lowes, Target	X	X				Trees n Trends	Speedway
US-231@Crossridge - Westpark	1438	00:20:A6:FF:B2:A3	PPG Paint, First Bank	X	X			875' WB, 1055' EB	Kentucky Auto Sales	Service One Credit Union
US-231@McIntosh	15582	04:F5:F4:00:29:B7	Crye-Leike	X	X			Replaced DSRC Radio 7/20/22	Destiny Ln	Between Chandler Memorial and Tree
US-231@Westen St	23043	04:F5:F4:00:2A:39	Family Video	X	X			1900' WB	Smallhouse Rd	Boost Mobile

Signal Location	Intersection ID	MAC Address	Landmark	SPaT	MAP	TIM	BSM	Notes	900' (to West)	900' (to East)
US-231@Smallhouse	24096	04:F5:F4:00:28:23	Giant Church	X	X				The Bungalows at B.G.	Western St
US-231@Thoroughbred Drive	25423	04:F5:F4:00:2A:49	Junior High	X	X			1115' EB	Little Caesars	House with iron fence
US-231@Harvard Blvd - Kroger	27019	04:F5:F4:00:28:2B	Cook Out	X	X			1200' WB	Speedway	Wild Eggs
US-231@US 31W (Nashville Rd)	28326	04:F5:F4:00:29:A3	Dollar Tree, Walgreens	X	X			1600' EB	Nova Center	UBreakIFix

Table 4 Field Validation Results for KY-876 (Richmond Bypass)

Signal Location	Intersection ID	MAC Address	Landmark	SPaT	MAP	TIM	BSM	Notes	900' (to West)	900' (to East)
KY-876@Goggins Lane	27747	04:F5:F4:00:29:6B	Garden Center	X	X	X	X	Enabled BSM Setting in MAXTIME cv — "Internal Messages", Tested sample TIM	St Thomas	Meijer gas
KY-876@Frankie Dr	26685	04:F5:F4:00:29:75	Raising Cane's	X	X		X	Enabled BSM Setting in MAXTIME cv — "Internal Messages"	Garden Center	Hampton Way
KY-876@Amberly Way	27153	04:F5:F4:00:28:5A	Shell/Circle K	X	X		X	Enabled BSM Setting in MAXTIME cv — "Internal Messages"	Idylwild Dr	Middle of Overpass
KY-876@I-75 SB Ramp	27642	00:20:A6:FF:B2:94	SB Ramp	X	X		X	Corrected MAP 7/21/22, Enabled BSM Setting in MAXTIME cv — "Internal Messages"	Back of Circle K	NB on Ramp Gore
KY-876@I-75 NB Ramp	27616	00:20:A6:FF:20:86	NB Ramp	X	X		X	Corrected MAP 7/21/22, Enabled BSM Setting in MAXTIME cv — "Internal Messages"	Adjacent to SB cabinet	BP
KY-876@Killarney	27590	00:20:A6:FF:B3:85	Cookout	X	X		X	Enabled BSM Setting in MAXTIME cv — "Internal Messages"	100' East of Overpass	Porter Dr.
KY-876@Porter	27561	04:F5:F4:00:2A:44	Hooters	X	X	X	X	Corrected MAP 7/21/22, Enabled BSM Setting in MAXTIME cv — "Internal Messages", Tested sample TIM	EB Stop Bar @ Killarney	Stop Bar in front of Chase Bank
KY-876@St George	27535	04:F5:F4:00:2A:35	Tokyo Express	X	X				Car-Mart	AT&T Store
KY-876@Brown	27496	04:F5:F4:00:2A:42	Speedway/Marathon	X	X				Arby's	Shell
KY-876@Lancaster Rd	26678	04:F5:F4:00:28:26	Penn Station	X	X				PNC Bank	Coliseum
KY-876@Coliseum	24343	04:F5:F4:00:29:6A	Coliseum	X	X				Lancaster	Kit Carson
KY-876@Kit Carson	21727	04:F5:F4:00:28:58	Stadium	X	X				Coliseum	Semi Parking by Football Field
KY-876@Hospital	16801	04:F5:F4:00:29:76	Hospital	X	X				Semi Parking by Football Field	Water Tower
KY-876@Boggs	13918	04:F5:F4:00:29:AA	Aldi	X	X				Water Tower	Chevy Dealership
KY-876@Mall	14646	04:F5:F4:00:28:54	KFC	X	X				O'Charley's	Office Depot
KY-876@Kroger	15888	04:F5:F4:00:29:6F	Office Depot	X	X				Red Lobster	Kroger Fuel
US-25@KY-876 / KY-25	20455	04:F5:F4:00:28:28	Kroger/Walgreens	X	X				Community Trust Bank	Batteries Unlimited

Signal Location	Intersection ID	MAC Address	Landmark	SPaT	MAP	TIM	BSM	Notes	900' (to West)	900' (to East)
US-25@Gibson Bay	34221	04:F5:F4:00:28:2D	Kentucky Bank	X	X				Pizza Hut	Kentucky National Guard
US-25@KY-52 (Irving Rd)	42908	04:F5:F4:00:29:A7	Dodge	X	X				Kid to Kid	Before Aaron's
US-25@Merrick Dr	10425	04:F5:F4:00:28:25	Kohl's	X	X				Miller's Tire	Central KY Ag Credit
US-25@Fourmile Rd	24550	04:F5:F4:00:28:34	BP/Toyota	X	X				Richmond Car and Truck Center	55 MPH speed limit sign
US-25@Union City Rd	54382	04:F5:F4:00:28:30	Dollar General	X	X				Beginning of Middle School	End of bridge
US-25@Old Wilderness Trail	55241	04:F5:F4:00:2A:3E	Street Sign	X	X				55 MPH speed limit sign	Elementary School
US-25@North Richmond	53594	04:F5:F4:00:29:6D	#16	X	X				Beginning of guard rail	Traffic signal ahead sign
US-25@I-75 NB Ramp	58509	04:F5:F4:00:28:1F	NB Ramp	X	X				75 South exit ramp	Barn
US-25@Keeneland Drive	63936	04:F5:F4:00:28:7E	Shell/Gulf	X	X				BP	75 South exit ramp