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MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

TRAVELER INFORMATION FOR RURAL MARYLAND

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16. Abstract

This project evaluated strategies for improving traveler-information dissemination in rural Maryland, with emphasis on areas historically served by Highway Advisory Radio (HAR). Effective traveler information is critical for routine traffic operations and emergency response, but rural corridors face challenges related to variable cellular coverage, sparse roadside infrastructure, and the need for timely guidance during adverse weather events, incidents, closures, evacuations, etc. HAR has historically provided localized traveler information in selected rural areas; however, aging infrastructure, limited geographic reach, maintenance burden, and changing traveler behavior have reduced its long-term viability. The project reviewed existing traveler-information technologies and practices, assessed communication challenges across major dissemination channels, and conducted field-based evaluation of cellular communication conditions along selected State Highway Administration (SHA)-maintained roadway corridors. Results indicate that cellular-based traveler information can play a major role in rural Maryland, although performance varies by carrier, corridor, and geography. Real-world Short Message Service and app-based message testing confirmed successful delivery under the tested roadway conditions, and measured cellular conditions within existing HAR service areas were generally sufficient relative to observed successful delivery thresholds. The study recommends retiring HAR as a routine dissemination channel and transitioning to a cellular-centered, Dynamic Message Sign-supported, multichannel framework that improves scalability, redundancy, and operational sustainability.

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Executive Summary

Effective traveler information is essential for safe and efficient transportation operations, particularly in rural areas and during emergencies. Highway Advisory Radio (HAR) has historically supported traveler-information dissemination in selected rural Maryland corridors, but aging infrastructure, maintenance requirements, and changing traveler behavior have reduced its long-term viability. This project evaluated whether modern communication approaches can reliably support areas historically served by HAR.

The project reviewed existing traveler-information technologies and practices and identified commercial cellular communication as the most practical near-term candidate for field evaluation because it is already widely deployed, can support multiple dissemination methods and does not require construction of a dedicated statewide roadside communication network. Field measurements showed that cellular performance varies by carrier, corridor, and geography but generally provides broader roadway coverage than the localized HAR service areas. Real-world testing using simulated Short Message Service (SMS) and app-based messages confirmed successful delivery under the tested conditions, and cellular conditions within the evaluated HAR service areas were generally at or above the weakest conditions associated with successful message delivery. These results indicate that cellular-based delivery can support the routine traveler-information function historically provided by HAR in the evaluated areas.

The findings support a layered system rather than replacement of HAR with a single technology. Cellular-based delivery can provide the primary routine communication pathway, while Dynamic Message Signs (DMS) provide direct roadside information at key locations. Although DMS do not require travelers to use a smartphone or data plan, individual signs may still depend on fiber, cellular, microwave, or other communications backhaul. Meanwhile, Wireless Emergency Alerts (WEA) through the Integrated Public Alert and Warning System (IPAWS) provide additional dissemination channels during emergency situations.

Based on these findings, Maryland Department of Transportation State Highway Administration (SHA) should first confirm replacement capability at HAR locations not

directly evaluated and develop a formal HAR decommissioning plan; next, retain and prioritize DMS at key locations while identifying critical backhaul dependencies; then expand reliance on cellular-based delivery, MD 511, and navigation platforms, with WEA/IPAWS used for appropriate life-safety events; and finally, monitor cellular coverage, message delivery, system availability, and redundancy as the transition proceeds. Overall, the project recommends retiring HAR as a routine traveler-information channel where replacement capability has been confirmed and transitioning to a cellular-centered, DMS-supported, multichannel framework.

Table of Contents

Executive Summary iv
Table of Contents vi
Chapter 1. Introduction 1
1.1 Background 1
1.2 Objectives 4
1.3 Report Organization 5
Chapter 2. Existing Technologies and Practices 6
2.1 Communication Technologies 6
2.2 Traveler Information Dissemination Methods 9
2.3 Best Practices and Performance Measures 19
2.4 Summary and Discussion 25
Chapter 3. Evaluation Methodology 27
3.1 Study Sites 27
3.2 Field Measurements of Cellular Signal Conditions 29
3.3 Real-World Traveler-Information Delivery Test 31
3.4 Assessment of Cellular Feasibility within Existing HAR Service Areas 33
Chapter 4. Evaluation Results and Findings 36
4.1 Cellular Signal Conditions in Rural Maryland 36
4.2 Results for Real-World Traveler-Information Delivery Test 42
4.3 Cellular Feasibility within Existing HAR Service Areas 45
4.4 Discussion 48
4.5 Implementation Recommendations 53
Chapter 5. Conclusion 55
References 57

Chapter 1. Introduction

1.1 Background

Effective traveler information is a cornerstone of modern transportation management. Whether supporting routine commutes or large-scale evacuations, traveler information that is timely, accurate, and actionable underpins every safe and efficient trip. On ordinary days, updates on congestion, work zones, and crashes help motorists avoid bottlenecks, freight carriers meet delivery windows, and emergency responders maintain reliable response times. On extraordinary days, when hurricanes, flash floods, wildfires, or hazmat incidents threaten lives, the same traveler information becomes a lifeline. For location-specific hazards such as flash-flood or high-tide locations, geofenced alerts could provide targeted warnings to travelers approaching or entering affected areas. Recent events illustrate this vividly: during Hurricane Sandy (2012), days-ahead forecasts and mandatory evacuation orders for low-lying coastal areas enabled authorities to move people out of harm's way. In Ellicott City (2016 and 2018), despite timely National Weather Service warnings, the rapid-onset flooding driven by extreme short-duration rainfall and steep urban topography still swept vehicles into danger. **Table 1** summarizes representative extraordinary events and traveler-information priorities, and **Figure 1** illustrates roadway and infrastructure damage from the 2016 Ellicott City flooding. These events demonstrate the critical importance of delivering timely, accurate, and actionable information to travelers, particularly during emergencies when conditions can change rapidly and communication failures can have serious consequences. This need provides the motivation for the project's evaluation of practical traveler-information strategies that can effectively reach motorists under varying roadway, geographic, and emergency conditions.



Figure 1. Destroyed Roads and Infrastructures of Ellicott City Inundations in 2016

Table 1 Representative Extraordinary Events and Traveler-Information Priorities

Event Type	Notable Examples (Location / Year)	Operational Impacts	Key Traveler Information
Hurricane / Tropical Storm	Hurricane Sandy (NJ/NY, 2012)[1]; Hurricane Ian (FL, 2022)[2]	Evacuations demand surge, bridge closures, storm-surge flooding	Evacuation routes, shelter guidance
Flash Flood	Ellicott City, MD (2016; 2018)[3], [4, p. 2]; Eastern Kentucky floods (2022)[5]	Rapid roadway inundation, washed-out bridges, low-water crossings	"TURN AROUND" flash alerts; road-closure status; alternate high-ground corridors
Wildfire	Camp Fire, CA (2018)[6]; Maui wildfires, HI (2023)[7]	Low visibility, evacuation demand surge, roadway closures	Evacuation routes/zones, wind-shift warnings, shelter guidance
Severe Winter Storm / Blizzard	I-95 Virginia gridlock (2022)[8]; Buffalo, NY blizzard (2022)[9]	Low visibility, snow/ice pile-ups, stranded vehicles, chain requirements	Road closure, warming-center sites, tow-and-recovery progress
Hazardous-Materials Release	East Palestine, OH train derailment (2023)[10]; US-15 Frederick, MD tanker explosion (2023)[11]	Toxic plumes, fire/explosion risk	Shelter-in-place vs. evacuate instructions; detour routes
Earthquake	Ridgecrest, CA earthquakes (2019)[12]; Anchorage area, AK earthquake (2018)[13]	Bridge/overpass integrity, rockfalls, signal outages	Bridge/route status; detour advisories; fuel & aid distribution points

State transportation agencies have long recognized this imperative and now deploy an increasingly diverse set of technologies to disseminate information to highway travelers. For example, traditional roadside Dynamic Message Signs (DMS) offer real-time and glance-readable advisories; Highway Advisory Radio (HAR), implemented as AM

Travelers' Information Stations (TIS) under Federal Communications Commission (FCC) rules, provides localized audio broadcasts (especially useful where cellular coverage is limited); the nationwide Wireless Emergency Alerts (WEA) program, and statewide 511 Traveler Information Systems integrate telephone, web, and mobile channels to aggregate traffic, weather, and transit data. Over the past decade, these legacy systems have been complemented, or in some cases supplanted, by digital platforms that reach travelers where they already spend their screen time: mobile push notifications, crowdsourced navigation apps such as Google Maps and Waze, and agency-curated social media feeds. Emerging connected-vehicle (CV) technologies now deliver sub-second, low-latency hazard messages directly to in-vehicle displays and Advanced Driver-Assistance Systems (ADAS), pointing toward a future of lane-level warnings enabled by roadside units (RSUs) and cellular-vehicle-to-everything (V2X). **Figure 2** illustrates HAR broadcasts on low-power AM and a WEA test notification on a traveler's phone.



Figure 2. Highway Advisory Radio (HAR) on Low-Power AM and Wireless Emergency Alerts (WEA) on a Traveler's Phone

Despite the breadth of available technologies and channels, stubborn blind spots persist in rural areas. In western Maryland's mountains, on the Lower Eastern Shore, and in parts of Southern Maryland, sparse towers and terrain create pockets of weak or no 4G LTE coverage, which limits the reach of phone-based advisories. HAR historically provided supplemental traveler information in some of these areas. However, Maryland

Department of Transportation State Highway Administration (SHA) faces many of the same pressures reported by other transportation agencies, including aging HAR equipment, limited availability of replacement parts, recurring maintenance requirements, and increasing difficulty sustaining the existing system. These conditions create a need to evaluate more sustainable approaches for maintaining reliable traveler-information coverage in rural areas.

The purpose of this project was to evaluate strategies for improving traveler-information dissemination in rural Maryland, particularly in the context of aging HAR infrastructure, limited rural DMS coverage, and variable cellular connectivity. The project assessed current challenges, reviewed alternative communication approaches, and evaluated their feasibility for supporting reliable traveler information in rural and emergency-sensitive corridors. The findings provide evidence-based guidance for modernizing rural traveler information and supporting SHA's transition toward a more reliable, scalable, and operationally sustainable communication system.

1.2 Objectives

This project aims to achieve the following objectives:

- Objective 1. Conduct a **comprehensive review** of existing traveler-information technologies, national practices, and emerging approaches for communicating with travelers in rural and emergency-sensitive environments.
- Objective 2. Assess **current traveler-information challenges** in rural Maryland, including aging HAR infrastructure, limited roadside communication coverage, and variable cellular connectivity.
- Objective 3. Evaluate the **feasibility and reliability of selected communication approaches** for delivering timely, accurate, and accessible traveler information under real roadway conditions.
- Objective 4. Develop **evidence-based implementation recommendations** to support SHA in modernizing rural traveler-information dissemination through a scalable, redundant, and operationally sustainable communication framework.

1.3 Report Organization

The remainder of this report is structured into four additional chapters:



Chapter 2. Existing Technologies and Practices

Reviews traveler-information technologies, national practices, HAR retirement trends, relevant policy requirements, and current Maryland traveler-information practices.



Chapter 3. Evaluation Methodology

Describes the study approach used to evaluate rural traveler-information alternatives, including field data collection, message-delivery testing, and assessment of communication feasibility within existing HAR service areas.



Chapter 4. Evaluation Results and Findings

Presents the results of the field evaluation, including cellular signal conditions, simulated message-delivery performance, HAR service-area feasibility, and spatial relationships among cellular coverage, DMS infrastructure, and HAR service areas.



Chapter 5. Conclusion

Summarizes the project approach, key findings, and implementation recommendations for modernizing rural traveler-information dissemination in Maryland.

Chapter 2. Existing Technologies and Practices

This chapter reviews existing traveler-information technologies, current policy and practice, HAR retirement trends, and relevant performance measures. The review identifies candidate communication technologies and dissemination methods, summarizes their relative maturity and operational characteristics, and provides the rationale for selecting cellular-based communication for field evaluation. Maryland-specific conclusions and recommendations are developed subsequently from the project's field results.

2.1 Communication Technologies

Cellular Technologies

Commercial cellular networks provide the underlying wireless communication infrastructure for several traveler-information dissemination methods, including Short Message Service (SMS), Wireless Emergency Alerts (WEA), mobile applications, and third-party navigation platforms. Current fourth-generation Long-Term Evolution (4G LTE) and fifth-generation (5G) networks provide broad coverage and data connectivity, although service availability and performance vary by carrier, geography, terrain, and network conditions.

Unlike agency-owned roadside communication infrastructure, cellular-based traveler-information delivery can use existing commercial wireless networks rather than requiring a dedicated agency-owned transmitter or roadside device at every location. The U.S. Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Deployment Evaluation cost database characterizes relevant cellular costs primarily as communications-service costs. Its adjusted estimates range from approximately $140 to $230 per year for low-usage wireless communications, $640 to $750 per year for medium usage, and $1,340 to $2,000 per year for high usage [14].

A limitation of commercial cellular infrastructure is its dependence on functioning network sites and backhaul. Major emergencies can disrupt this infrastructure and reduce

the availability of all dissemination methods that rely on the affected network. During the August 2023 Maui wildfires, Federal Communications Commission (FCC) status reports indicated that up to 20 of the 21 cell sites serving West Maui were out [15]. This experience illustrates why cellular communication, although mature and broadly available, should be incorporated into a layered system with alternative communication pathways for major emergencies.

Legacy cellular technologies may also warrant further evaluation for emergency communication in sparsely populated rural areas. 2G and 3G networks have historically operated in lower-frequency bands and with larger cell footprints, allowing signals to cover wider areas with fewer towers than many 4G and 5G deployments. In some configurations, 2G can provide even greater coverage than 3G, which may make these technologies useful for maintaining emergency-alert capability in remote, low-density regions while reducing infrastructure requirements. However, these advantages are driven largely by frequency, network design, and terrain rather than the cellular generation itself. Low-band 4G LTE and 5G can similarly provide greater coverage and require fewer towers than higher-frequency deployments. In addition, many commercial 2G and 3G networks have already been retired. A future feasibility study could therefore assess whether remaining or purpose-built low-band cellular infrastructure could provide a practical emergency-messaging fallback in rural Maryland, considering coverage, spectrum availability, device compatibility, infrastructure cost, and long-term support.

Satellite-Based

Low Earth Orbit (LEO) constellations, as shown in **Figure 3**, are transforming what was once a niche market for satellite messengers [16]. Regulatory momentum is accelerating. In March 2025, the Federal Communications Commission (FCC) conditionally granted SpaceX a waiver allowing its direct-to-cell Supplemental Coverage from Space operations with T-Mobile to operate under a higher aggregate out-of-band power limit, subject to requirements to address harmful interference to adjacent terrestrial wireless networks [17]. Proof-of-concept efforts began earlier; in September 2024 [18], T-Mobile and SpaceX demonstrated the first U.S. Wireless Emergency Alert delivered via a

Starlink direct-to-cell satellite. Operators were able to queue and deploy the alert in seconds and which was received on standard LTE-capable phones. In parallel, mass-market smartphones now support person-to-agency satellite texting when terrestrial networks are unavailable: Apple's Emergency SOS via satellite (iPhone 14 or later) and Google's Satellite SOS on Pixel devices allow users to text emergency services without external antennas [19], [20]. Dedicated satellite messengers and handsets still offer longer battery life and two-way group messaging; however, device and subscription costs remain barriers to broad adoption [21].



Figure 3. Low-Earth-Orbit Constellations Example

Other wide-area non-terrestrial communication options include High-Altitude Platform Systems (HAPS) and commercial satellite radio. HAPS use long-endurance aircraft, balloons, airships, or other platforms operating in the upper atmosphere. The International Telecommunication Union (ITU) defines HAPS as radio stations located on objects operating approximately 20 to 50 km above the Earth. Their altitude allows them to provide coverage over relatively large areas, and potential applications include broadband access and backhaul in remote or underserved areas and communications support when terrestrial networks are disrupted by disasters [22]. These characteristics may make HAPS relevant to rural transportation corridors or emergency situations where

terrestrial communications infrastructure is sparse or temporarily unavailable.

Connected Vehicles

Emerging connected-vehicle (CV) technologies can also disseminate traveler information. On Wyoming's 402-mile I-80 corridor shown in **Figure 4**, the U.S. DOT CV Pilot initially used Dedicated Short-Range Communications (DSRC) to deliver sub-second (< 1 s) hazard advisories directly to equipped commercial vehicles, while integrating the same events into WYDOT's traveler-information channels (for example, 511). Following the FCC's spectrum action, the pilot began a Phase 4 conversion to cellular V2X (C-V2X) [23], [24], [25], [26], [27]. The challenge is that only a fraction of the fleet is CV-ready today, so conventional signs and app-based channels remain indispensable for the coming years.

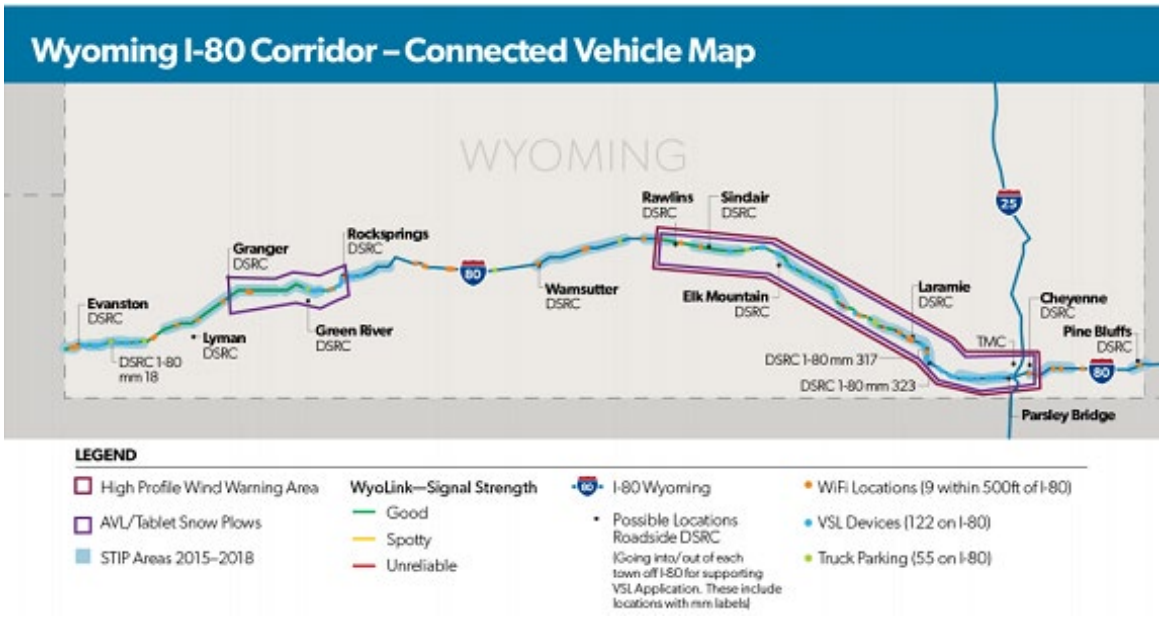


Figure 4. Wyoming Interstate 80 Corridor — Connected Vehicle Pilot Map (source: Wyoming Department of Transportation [28])

2.2 Traveler Information Dissemination Methods

Roadside

Dynamic Message Signs (DMS), as shown in **Figure 5**, are electronic systems that

disseminate real-time traffic information to improve safety and network efficiency. DMS remain the primary roadside medium for traveler information. Benefits include instantaneous, at-a-glance legibility and independence from traveler smartphone ownership or data plans; limitations include wider spacing outside metropolitan areas because of capital cost. In rural areas, the sign head alone typically costs tens of thousands of dollars. Where bridge widening, power service, or fiber backhaul are required, total installed costs can exceed $300,000 per location; for example, installations in mountainous corridors such as Glenwood Canyon, CO, have been reported at approximately $321,000 when structural and fiber work are included [29]. The USDOT ITS Deployment Evaluation cost database estimates DMS equipment at approximately $34,950 to $87,010 per unit in 2020-adjusted dollars, excluding installation. Supporting DMS structures range from approximately $31,580 for smaller arterial structures to $251,450 for larger structures spanning three to four lanes. The communications dependency of DMS should also be distinguished from its traveler-facing function. DMS provides direct roadside information without requiring the traveler to have a smartphone or data plan, but remote sign operation may depend on wireline, fiber, wireless, or other communications backhaul. For example, the database estimates wireline connections to roadside message signs at approximately $6,410 to $9,620, while fiber-optic installation can vary substantially depending on site conditions. These costs help explain why DMS are generally concentrated at higher-priority locations rather than continuously deployed along rural corridors. Annual DMS operations and maintenance costs are estimated at approximately $1,710 to $4,460 per sign [14].

The content that DMS can convey is also constrained. The 11th Edition of the Manual on Uniform Traffic Control Devices (MUTCD) (December 2023) establishes updated requirements for DMS [30]. For permanent signs, messages are limited to a maximum of three lines with no more than 20 characters per line. For portable changeable message signs used in work zones, the guidance is three lines of eight characters per line or use of a full-matrix display. The MUTCD further restricts phasing and exposure: no more than two phases per message, a minimum of 2 seconds per phase, and a maximum cycle time of 8 seconds, with an inter-phase interval of 0.3 seconds or less. It also emphasizes concise, traffic-relevant wording with standard abbreviations; in short, simple, direct, action-

oriented phrasing that supports rapid comprehension at highway speeds.



Figure 5. DMS in Maryland [source: Coordinated Highways Action Response Team (CHART) homepage [31]]

Highway Advisory Radio (HAR) is low-power, non-commercial AM radio service that provides motorists with real-time information on traffic, weather, construction, and other travel-related topics. HAR historically mitigated rural coverage gaps through Travelers' Information Stations (TIS); however, many transmitters are at or near end of life, and audience reach is declining. For comparison with DMS, the USDOT ITS Deployment Evaluation cost database estimates the capital cost of a 10-watt HAR installation at approximately $17,530 to $40,910 in 2020-adjusted dollars, with annual operations and maintenance costs of approximately $700 to $1,170 per unit. A HAR sign with flashing beacons adds approximately $3,720 to $6,690 in capital cost [14]. At the same time, in several states, HAR may continue to provide value in specialized settings, such as mountain passes, evacuation corridors, long-duration work zones, or temporary deployments where alternative communication channels are limited and existing equipment remains serviceable.

Cellular-Based and Mobile

Cellular networks support several distinct traveler-information dissemination methods with different operational purposes. The most pervasive delivery channel today remains the cellular phone [32]. For routine traveler information, SMS can provide targeted

or corridor-wide information using existing commercial cellular networks. For life-safety emergencies, Wireless Emergency Alerts provide a separate mechanism for rapidly reaching compatible mobile devices within a defined geographic area.

The Integrated Public Alert & Warning System (IPAWS) delivers Wireless Emergency Alerts (WEA) to mobile devices with a distinct attention signal and vibration pattern. While most alert classes are user-configurable, users cannot opt out of National Alerts, and devices deliver WEA messages promptly without preempting an active call or data session. Many devices present WEAs even when set to silent (subject to device settings). Since March 2025, alert originators may also select "silent" WEAs for sensitive situations.

Federal Emergency Management Agency (FEMA)'s October 2023 update confirms support for up to 360-character WEAs, English/Spanish alerting, and device-based geo-targeting on LTE/5G [15]. To maximize delivery across mixed device types, alert originators should include both a 360-character and a 90-character field in the same alert; participating providers will deliver the 360-character version to LTE/5G-capable devices and the 90-character version to legacy handsets [33].

Reverse-911–style voice calls and SMS notifications complement WEA where opt-in registries are robust, and the 511 telephone service continues to serve motorists who prefer hands-free audio prompts or who rely on legacy feature phones [34].

Cellular dissemination should also be complemented by methods that do not depend on the same commercial cellular pathway. FM broadcast provides a low-latency, power-efficient backup via live cut-ins and RDS/Alert FM datacasting; satellite channels and roadside DMS serve as additional backstops [35]. RDS subcarrier datacasting can distribute short alerts; however, very low throughput (approximately 1,187.5 bps) and limited access to FM receivers in smartphones, particularly iPhones, constrain audience reach without dedicated receivers. Controlled studies of 511 Interactive Voice Response (IVR) use while driving report more frequent braking and an approximately three- to four-fold increase in crash risk compared with non-users; programs therefore emphasize shorter prompts, pre-trip use, or links that transition users to apps or SMS instead [36]. Taken together, these

findings support multi-layer strategies that pair high-reach cellular warnings with non-cellular fallbacks to maintain continuity of public warning [37].*Internet and App-Based*

Smartphone navigation apps have become de facto situational-awareness dashboards and integrate well with modern in-vehicle interface platforms [38]. Google Maps, Apple Maps, and Waze crowdsource incident reports (**Figure 6**) and can reroute drivers within seconds [39]. Agencies now syndicate their own events into these ecosystems; Oregon DOT's TripCheck, for example, funnels official closures into a website that receives hundreds of thousands of visits per day [37]. Its API serves approximately 30 million requests per day, and the JSON feeds propagate to Google, Apple, Waze, and OEM dashboards within minutes, illustrating how a single authoritative source can populate multiple consumer surfaces at negligible marginal cost.

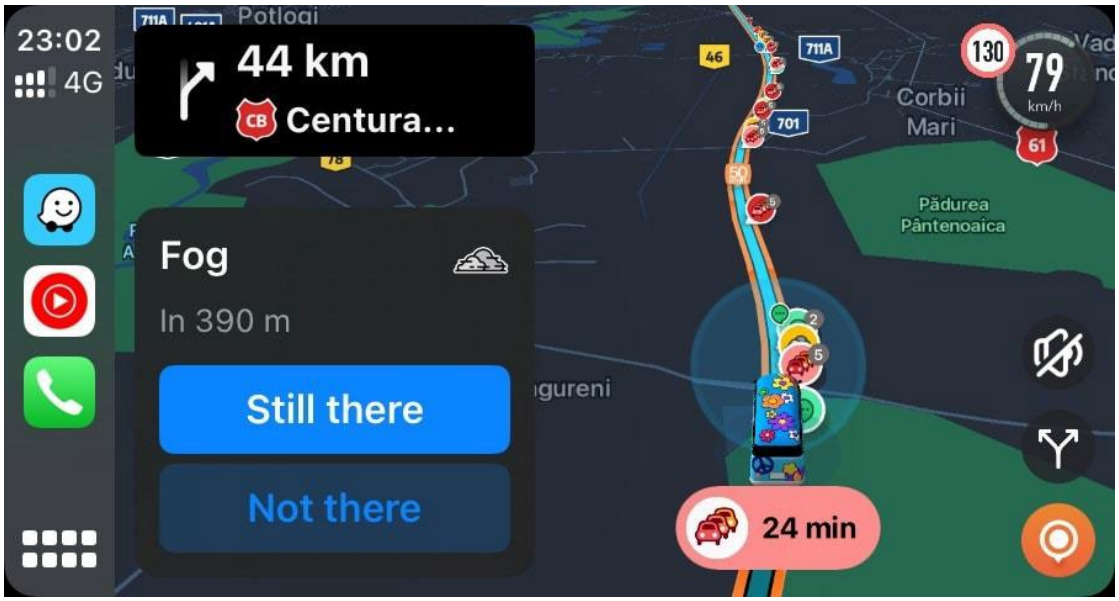


Figure 6. Waze Real-Time Event Display on Apple CarPlay

Social media can extend reach, but noisy timelines and algorithmic ranking can throttle official posts, burying urgent updates beneath high-engagement entertainment content [40], [41]. Analyses of Twitter/X activity during hurricanes indicate that these ranking effects can delay exposure to official warnings by hours. In response, agencies are testing designated priority handles and paid amplification to improve delivery during time-critical incidents.

Access to personal mobile technology should also be considered when prioritizing traveler-information channels. The 2024 American Community Survey indicates that 94.4 percent of Maryland households have a broadband Internet subscription, leaving approximately 5.6 percent without broadband access [42]. Nationally, 87 percent of rural adults reported owning a smartphone in 2025, while 97 percent owned some type of cellphone [43]. These data indicate that smartphone-based services can reach most rural travelers but should not be used as the sole dissemination method. DMS, SMS, and Wireless Emergency Alerts remain important for travelers who do not own smartphones, lack mobile data access, or do not actively use traveler-information applications.

Satellite Radio

Commercial satellite radio represents a different type of wide-area communication option. Unlike emerging direct-to-device satellite services, satellite radio is an established broadcast service and has previously been identified by FHWA as an Advanced Traveler Information System dissemination mechanism. FHWA notes that satellite radio is generally a privately owned communication channel and that traveler information distributed by private providers can originate from both public- and private-sector sources [44]. Satellite radio may therefore provide a supplemental means of disseminating traveler or emergency information over a broad geographic area, although the State DOT typically would not exercise the same level of control over the service as it does over agency-operated systems such as Dynamic Message Signs (DMS).

From a State DOT perspective, HAPS and direct-to-device satellite services are better considered potential supplemental communication paths than direct replacements for established traveler-information systems. Satellite communications can also provide an alternate communication path for remote sites or emergency operations when terrestrial networks are unavailable. Federal emergency-communications guidance identifies satellite communications as a viable backup when severe events damage earth-based communications infrastructure [45]. For transportation applications, agencies should evaluate latency, available capacity, coverage and service commitments, equipment requirements, interoperability with existing ITS and traffic-management systems, agency

control, and recurring service fees as part of total cost of ownership.

Future research should evaluate the technical, operational, institutional, and cost feasibility of HAPS, direct-to-device satellite services, and other emerging non-terrestrial communication technologies for rural traveler information, emergency communication, and Intelligent Transportation Systems infrastructure in Maryland. Such research could consider targeted pilot applications, including emergency alert dissemination, backup connectivity for remote ITS sites, and coverage extension in locations where terrestrial communications infrastructure is sparse or disrupted.

Smart City and IoT Approaches

Several Internet of Things (IoT) approaches rely on Bluetooth Low Energy and other proximity technologies to deliver resilient, location-targeted traveler information where GPS or cellular coverage is constrained (tunnels, urban canyons, mountainous rock cuts). Waze Beacons broadcasting Bluetooth Low Energy (BLE) identifiers preserve turn-by-turn navigation [46]. To address tunnel blackouts, cities from Pittsburgh to Paris have adopted Waze Beacons, which are battery-powered BLE transmitters costing about $30 each; approximately 42 units are needed per mile, yielding an installed cost near $1,200 per mile and providing uninterrupted navigation without carrier infrastructure. At the curb, University of Alabama researchers estimate that deploying StreetBit BLE beacons at 10 percent of signalized intersections would yield approximately US $18 million per year in avoided pedestrian injuries [47].

Moving beyond broad-area broadcasts, geofencing enables agencies to target alerts only to devices that cross a defined perimeter, which is useful for localized hazards such as low-clearance bridges or a wildfire flare-up confined to a single valley [48], [49]. Geofencing is progressing from pilot to practice: UK freight operators are deploying geofenced alerts and vehicle controls (for example, speed or torque limiting when a truck approaches a low-clearance bridge), demonstrating how warnings can trigger preventive control rather than simple notifications [50].

On the horizon, AI-powered chatbots are beginning to field traveler questions around

the clock, triaging routine inquiries so human operators can focus on complex events. These tools depend on authoritative back-end data and introduce governance requirements for message review and mitigation of hallucination risk.

Overall, the traveler-information system functions as a layered net. Roadside infrastructure (for example, DMS and connected-vehicle-to-infrastructure) provides deterministic coverage where installed, but it is capital intensive to build and maintain. Cellular channels offer wide reach at low marginal cost, yet they are vulnerable to dead zones and disaster-related outages. Satellite links can backfill coverage but require a clear sky view and entail recurring service charges. Internet applications and social platforms leverage habitual user behavior and can accelerate diffusion, but they cannot guarantee prominence in algorithmic feeds and therefore complement, rather than replace, authoritative alerting. Smart city and IoT tools enable highly localized cues and conversational guidance, while introducing requirements for privacy, cybersecurity, and data governance. Table 2 compares the principal traveler information technologies across coverage characteristics, advantages, and limitations.

In practice, travelers do not rely on a single source. Field and survey evidence show that motorists combine HAR, smartphone apps, DMSs, and agency alerts, with preferences varying by trip phase (pre-trip versus en-route), perceived severity, and driving workload [51]. In Maryland, severe-weather traveler-information practice routinely pushes 511 web service and social channels in parallel, reflecting a redundancy doctrine [33], [52]. During winter storms, SHA has explicitly encouraged parallel channel use. For example, a statewide advisory on February 21, 2015 urged motorists to stay off the roads and directed them to utilize the MD 511 service and follow SHA on Twitter and Facebook, illustrating how agencies now promote multi-channel reach [52].

Accordingly, an effective rural strategy blends at least two channels with complementary failure modes, such as a ground-based path for day-to-day advisories paired with a broadcast or satellite fallback that persists when poles, fiber, or towers are impaired. This multi-modal, redundant approach aligns with federal public-alerting guidance.

A brief summary of all technologies and their characteristics is shown in **Table 2**.

Among the travel information dissemination methods reviewed, commercial cellular communication represented the most mature and scalable candidate for near-term field evaluation because it already supports multiple traveler-information channels, including Short Message Service (SMS), mobile applications, 511-related services, Wireless Emergency Alerts (WEA), and third-party navigation platforms. The principal uncertainty for rural Maryland was therefore not whether these services exist, but whether field-measured cellular conditions are sufficiently reliable along rural corridors and within areas historically served by HAR. This question became the focus of the field evaluation described in Chapter 3.

Table 2. Traveler Information Dissemination Methods Characteristics Summary

Technology	Maturity	Coverage	Capital Cost	Operating Cost	Resilience	Scalability	Routine vs Emergency
Dynamic Message Signs (DMS)	Established	Corridor-based; limited in rural areas due to cost	High	Low to moderate	High roadside visibility; backhaul dependent	Low-Moderate	Both
Highway Advisory Radio (HAR)	Legacy	Approximately 3 to 5 miles radius per transmitter; receiver-dependent	Low-Moderate	Moderate/high for aging system	Localized, independent of traveler cellular data	Low	Both
Cellular, SMS, and app-based delivery (including WEA)	Established	Nationwide with network coverage; voice/SMS can function without data	Low agency cost	Low to moderate	Vulnerable to coverage gaps and outages	High	Both
Connected Vehicle (DSRC/CV2X)	Early-stage	Roughly 300 m roadside range; <10% fleet penetration	Moderate to high	Moderate	Potential direct vehicle communication	Low	Routine
Satellite-based messaging	Early-stage	Near-global with line of sight; infrastructure-independent	No DOT deployment cost identified	No DOT deployment cost identified	Potential fallback to terrestrial networks	High potential	Emergency
Internet & App-Based (Maps, 511 Websites)	Established	Available with cellular/Wi-Fi; limited in tunnels and urban canyons	Low roadside cost; platform costs vary	Low to moderate	Cellular/data dependent	High	Both
Smart City & IoT (Beacons, Geofencing)	Early-stage	About 50–100 m beacon/geofence range; works indoors/underground	Low to moderate	Low to moderate	Useful for localized gaps	Low	Routine

2.3 Best Practices and Performance Measures

Policies and Current Maryland Practice

At the federal level, the Real-Time System Management Information Program (23 CFR Part 511) requires states to establish real-time programs that cover all Interstate highways [53]. The rule sets timeliness targets by information type:

- Full lane or road closures and reopenings due to construction, and verified lane-blocking incidents, must be made available within 10 minutes in metropolitan areas and within 20 minutes elsewhere.
- Roadway weather observations, including hazardous conditions and weather-related closures or blockages, must be available within 20 minutes statewide.
- Travel-time information on limited-access segments in metropolitan areas must be available within 10 minutes of the travel-time calculation.
- Minimum design thresholds include at least 85 percent information accuracy and at least 90 percent system information availability.

Maryland complements these federal requirements with the statewide Clear-the-Road / Move It quick-clearance policy, jointly endorsed by SHA and the Maryland State Police [54]. Under the SHA–MSP Traffic Incident Management Memorandum of Understanding, the target clearance time is 90 minutes, measured from the arrival of the authorized relocation, towing, and recovery service. The MOU designates the CHART Statewide Operations Center (SOC) as the clearinghouse for verified incident information and the hub for dissemination. The CHART SOC integrates the statewide Dynamic Message Sign (DMS) network; the MD 511 web service (CHART Web is Maryland's official 511); and crowdsourced inputs via the Waze partnership [31], [55]. When a life-safety threat warrants public warning beyond roadside devices, agencies coordinate with authorized Alerting Authorities (for example, MDEM or county OEMs) to issue WEA via IPAWS [33], [56], [57], [58], [59]. These processes promote accuracy and timeliness; however, they cannot ensure signal availability in Maryland's most remote corridors, where geographic reach remains the primary vulnerability rather than regulatory non-compliance.

Phasing Out and Repositioning of HAR

Across the United States, agencies are repositioning Highway Advisory Radio (HAR) as equipment reaches end of life, audience penetration declines, and mobile-first channels expand. Routine traveler information now flows primarily through 511 websites and apps, Dynamic Message Signs (DMS), and agency social media, while HAR is reserved for niche roles such as mountain passes, evacuation or toll corridors, and long-duration work zones. Multi-state reviews identify four common responses: decommission legacy AM transmitters; replace in-vehicle audio with "virtual HAR" (hands-free, geofenced voice in official 511 applications); repurpose remaining sites or signage; and retain limited or portable transmitters for special operating contexts [60].

Several states have completed formal retirements. Idaho decommissioned its statewide HAR network in April 2020 and shifted alerts to non-HAR channels, including 511 and DMS [61]. Missouri eliminated HAR in 2013–2014 except where required for tunnels; roadside signs were removed, broadcasts were turned off, and hardware was taken out during roadway projects. Functionality moved to MoDOT's traveler information map and app, along with third-party navigation platforms [60]. Iowa eliminated HAR in December 2016 through a stepwise plan that severed the CARS/511 feed, removed roadside "tune to" signs, and allowed FCC licenses to expire; ongoing traveler information is provided via 511, DMS, broadcast outlets, and agency digital channels. Iowa retains portable units for rare, high-impact incidents, but routine information now uses non-HAR channels [60]. Indiana removed HAR from its Intelligent Transportation Systems standards and catalog in 2022, confirming that the technology is no longer in use; traveler information is delivered through 511IN/TrafficWise on the web and mobile, supported by DMS [62]. Oklahoma retired HAR statewide; the 2023 strategic plan notes that transmitters and related infrastructure are no longer in service and are being retired as hardware ages out. The state now emphasizes Drive Oklahoma (mobile app), the OKTraffic real-time map with cameras and message signs, a road-conditions hotline for weather and emergencies, and DMS [63]. Rhode Island phased out HAR on 1630 AM in fall 2021 as obsolete and now relies on DMS, 511, and social channels [64].

Other states are adopting "virtual HAR." New Jersey's approach centers on SafeTripNJ, a hands-free, GPS-triggered audio application that reads NJ511 advisories in the vehicle, preserving the in-vehicle audio use case without AM transmitters [65]. Pennsylvania is retiring legacy HAR while migrating functionality to geofenced, 511-based voice over the IVR channel; during extended closures or severe weather, information is distributed via DMS in coordination with 511 calls, and modified HAR signs are used to direct motorists to current updates [60].

Massachusetts has phased out day-to-day HAR but maintains portable units at district offices for project-specific deployments such as major work zones. Wisconsin is retiring HAR by attrition, citing limited coverage and declining in-vehicle AM receivers, while upgrading the 511 phone service and web or app delivery [60].

Taken together, the dominant operating model is 511-first, with DMS and emergency alerts orchestrated in parallel. Agencies that exit AM transmitters typically migrate the in-vehicle audio use case to hands-free, geofenced voice in 511 applications, or retain portable transmitters for special events and extended work zones. Where HAR is retired, common practices include repurposing signage to direct motorists to 511, salvaging components to sustain a few remaining locations during transition, and formalizing decommissioning steps such as license management, hardware removal, and customer messaging.

Table 3 catalogs each state's 511 brand and primary access channels. The entries show near-universal availability of a branded 511 platform, with web maps and mobile apps as the default access modes. Many states also maintain the 511 phone service for hands-free and equity needs. Overall, the table illustrates the shift to 511 and DMS as core dissemination channels, which supports the phase-out of legacy HAR while preserving in-vehicle audio through app-based, hands-free features.

Table 3. State Travel Information Programs Details

State	Program Brand	Primary Access Channels
Alabama	ALGO Traffic	Web: ALGOtraffic.com; Mobile App
Alaska	Alaska 511	Web: 511.alaska.gov; Mobile App
Arizona	AZ511	Web: az511.gov; Mobile App
Arkansas	IDriveArkansas	Web: IDriveArkansas.com; Mobile App

California	QuickMap	Web: quickmap.dot.ca.gov; Mobile App; Phone: 1-800-427-7623
Colorado	COtrip	Web: COtrip.org; Mobile App; Phone: 511
Connecticut	CT Travel Smart (CT511)	Web: portal.ct.gov/DOT; Phone: 511
Delaware	DelDOT Traffic	Web: deldot.gov; Mobile App
Florida	FL511	Web: FL511.com; Mobile App; X/Twitter
Georgia	511GA	Web: 511ga.org; Mobile App; Phone: 511
Hawaii	GoAkamai	Web: GoAkamai.org; Phone: 511
Idaho	Idaho 511	Web: 511.idaho.gov; Mobile App
Illinois	Getting Around Illinois	Web: gettingaroundillinois.com
Indiana	511IN (Trafficwise)	Web: 511in.org; Mobile App
Iowa	Iowa 511	Web: 511ia.org; Mobile App
Kansas	KanDrive	Web: kandrive.org; Mobile App; Phone: 511
Kentucky	GoKY	Web: GoKY.ky.gov
Louisiana	511LA	Web: 511la.org; Mobile App; Phone: 511 / 888-ROADS-511
Maine	New England 511	Web: newengland511.org
Maryland	CHART / MD511	Web: chart.maryland.gov
Massachusetts	Mass511	Web: mass511.com; Mobile App
Michigan	Mi Drive	Web: michigan.gov/drive
Minnesota	Minnesota 511	Web: 511mn.org; Mobile App
Mississippi	MDOT Traffic	Web: mdottraffic.com; Mobile App
Missouri	Traveler Info Map	Web: traveler.modot.org; Mobile App
Montana	Montana 511	Web: 511mt.net; Phone: 511; Mobile App
Nebraska	Nebraska 511	Web: 511.nebraska.gov; Phone: 511; Mobile App
Nevada	511 Nevada Travel Info	Web: nvroads.com; Mobile App
New Hampshire	New England 511	Web: newengland511.org
New Jersey	511NJ	Web: 511nj.org; Phone: 511; Mobile App
New York	511NY	Web: 511ny.org
North Carolina	DriveNC.gov	Web: DriveNC.gov; Phone: 511; Mobile App
North Dakota	ND Roads / ND 511	Web: travel.dot.nd.gov; Phone: 511; Mobile App
Ohio	OHGO	Web: OHGO.com; Mobile App
Oklahoma	OKTraffic	Web: oktraffic.org; Phone: 511; Mobile App
Oregon	TripCheck	Web: TripCheck.com
Pennsylvania	511PA	Web: 511PA.com; Phone: 511; Mobile App
Rhode Island	(No single brand)	Web: dot.ri.gov
South Carolina	511SC	Web: 511sc.org; Phone: 511; Mobile App

South Dakota	SD511	Web: sd511.org; Phone: 511; Mobile App
Tennessee	TN SmartWay	Web: smartway.tn.gov; Phone: 511
Texas	DriveTexas.org	Web: DriveTexas.org
Utah	UDOT Traffic	Web: udot.utah.gov/traffic; Mobile App; Phone: 511
Vermont	New England 511	Web: newengland511.org
Virginia	511 Virginia	Web: 511virginia.org; Mobile App; Phone: 511
Washington	(No single brand)	Web: wsdot.wa.gov; Mobile App; Phone: 511
West Virginia	WV511	Web: wv511.org; Phone: 511
Wisconsin	511 Wisconsin	Web: 511wi.gov; Mobile App; Phone: 511
Wyoming	Wyoming 511	Web: wyoroad.info; Mobile App; Phone: 511

Effectiveness and Its Measurement

Effectiveness can be assessed along two dimensions: delivery and understanding. Reach and delivery analytics establish exposure and latency. Useful indicators include the percentage of devices within an alert polygon that successfully received a Wireless Emergency Alert, the open and click-through rates for MD 511 web service, and Dynamic Message Sign uptime [66].

Comprehension and recall testing confirms that messages are interpreted as intended. Laboratory, simulator, and roadside studies can verify whether travelers correctly understand wording and symbols. Maryland simulator results indicate that brief, single-concept DMS messages produce higher recall and more reliable route choice than longer, multi-panel formats, which supports strict brevity rules and standardized templates [67], [68].

Message modality should also be treated as a design consideration independent of the communication technology. Visual messages are appropriate where information can be conveyed safely through DMS, maps, websites, or other displays, while audible delivery can reduce visual demand for travelers in motion when provided through passive or hands-free systems. Under routine conditions, visual information can serve as the primary modality, with audible information available as a supplement. For urgent en-route events, brief visual messages should be reinforced by short audible alerts where supported. For life-safety events, both visual and audible channels should be used where practical to maximize reach and redundancy. Across all modalities, the underlying information should

remain consistent, while message length, detail, and presentation should be adapted to roadway context and traveler workload.

Accordingly, a layered traveler-information system should incorporate both technology redundancy and modality redundancy, presenting information differently across technologies based on roadway context, event severity, and traveler workload.

Potential Funding Mechanism

Federal funding and research initiatives operationalize the statutory framework and accelerate adoption of next-generation traveler information. Under 23 CFR Part 511, projects that establish or enhance real-time information programs are eligible for a federal share up to 90 percent on Interstate facilities and 80 percent on non-Interstate segments (23 U.S.C. §120). States typically apply these shares to deploy DMSs, expand detection networks, and build backhaul (fiber, microwave, or, where justified, satellite) to extend coverage on low-volume rural corridors.

IPAWS is hosted by FEMA; sending alerts has no transmission fee, although agencies generally procure IPAWS-compatible origination software [57]. USDOT research programs, including the ITS Joint Program Office portfolio [69] and the Connected Vehicle Pilot Deployment Program [23], further advance deployment.

The Bipartisan Infrastructure Law (IIJA, FY 2022 to 2026) adds broadband and ITS grants that help close rural backhaul gaps and seed pilots. NTIA's BEAD program targets unserved and underserved broadband-serviceable locations, and the Enabling Middle Mile program funds middle-mile infrastructure to lower transport costs. These funds are commonly used to build fiber or microwave backhaul for future rural DMS and roadside unit clusters; low Earth orbit satellite may be used only when it meets BEAD performance thresholds and terrestrial options are impracticable [70].

USDOT's ATTAIN [71] and SMART [72] programs provide competitive funding for ITS-oriented deployments through 2026. Taken together, these programs enable agencies to extend coverage, modernize dissemination channels, and harden rural corridors against outages.

2.4 Summary and Discussion

The technology landscape functions as a layered system that pairs day-to-day cellular delivery with resilient fallbacks. Dynamic Message Signs remain the primary roadside medium, reliable once installed yet constrained by capital cost and MUTCD brevity limits. Cellular paths carry most routine load through 511 apps and websites, Wireless Emergency Alerts with device-based geo-targeting and longer fields on modern devices, and navigation platforms that ingest agency feeds; social channels add reach but are subject to algorithmic ranking. Continuity during outages is supported by broadcast and satellite options, including FM cut-ins and RDS/Alert FM, selective use of portable or niche Highway Advisory Radio, and satellite backhaul or direct-to-cell pilots with cost and latency tradeoffs. Location-targeted tools extend precision where GPS and coverage are challenged, such as BLE beacons in tunnels and canyons, geofenced alerts for localized hazards, and connected-vehicle pilots that deliver low-latency warnings despite limited fleet penetration.

Policy and practice align around concise, authoritative messages delivered through a multichannel architecture. 23 CFR Part 511 sets scope, timeliness, accuracy, and availability; MUTCD and FHWA human-factors guidance drive short, single-concept wording that supports rapid comprehension. Maryland implements this baseline through Clear-the-Road / Move It, the CHART Statewide Operations Center that integrates DMS, MD 511 web service, and Waze inputs, and coordination with Alerting Authorities to issue Wireless Emergency Alerts via IPAWS; remaining risk centers on uneven rural coverage. Nationally, agencies are retiring or narrowing legacy HAR, adopting virtual HAR in 511 apps, and operating a 511-first model with DMS and emergency alerts in parallel. Programs evaluate effectiveness on delivery and understanding, with behavior change as the objective, and use federal cost shares and IIJA programs such as BEAD, Enabling Middle Mile, ATTAIN, and SMART to fund coverage, backhaul, and modernization.

Cost is another important consideration when comparing these near-term traveler-information approaches. **Table 4** provides a planning-level comparison of DMS, HAR, and cellular-based communication, illustrating the different capital and operating cost

structures associated with each approach.

Table 4. Planning-Level Cost Comparison of Selected Traveler-Information Technologies

Technology	Capital Cost	Annual O&M
DMS	$34,950-$87,010/unit, excluding installation; structure $31,580-$251,450	$1,710-$4,460/unit
HAR	$17,530-$40,910/unit; HAR sign $3,720-$6,690	$700-$1,170/unit
Cellular	Uses existing commercial infrastructure	Approx. $140-$2,000

Within this context, the most practical replacement for routine HAR service is not another single-purpose communication technology, but a cellular-centered, DMS-supported traveler-information system. HAR historically provided supplemental in-vehicle audio messaging in selected corridors; however, its role has diminished as equipment ages, audience reach declines, and traveler information increasingly shifts toward 511 systems, mobile applications, third-party navigation platforms, DMS, and emergency alerting systems. Cellular-based channels provide broad reach and low marginal cost through SMS, app-based notifications, MD 511-related services, WEA/IPAWS, and navigation platforms. DMS remains essential because it provides direct roadside visibility without requiring travelers to own a smartphone, maintain a data plan, or actively use an application. Maryland already operates within a strong policy and operational framework. CHART, MD 511 web services, DMS, Waze integration, and coordination through IPAWS for Wireless Emergency Alerts form a capable core for day-to-day operations and life-safety alerts. The remaining gaps are primarily physical rather than procedural: sparse towers, challenging terrain, and long distances can reduce cellular reliability and limit the reach of phone-based advisories. Therefore, the review indicates that the preferred post-HAR strategy is to retire HAR as a routine dissemination channel and replace it with a layered system that uses cellular communication as the primary delivery pathway, DMS as the principal roadside visibility layer, and CHART/MD 511, WEA/IPAWS, navigation platforms, and targeted fallback technologies as supporting channels.

Chapter 3. Evaluation Methodology

This project developed and applied an empirical evaluation framework to determine whether cellular-based traveler information can support traveler-information dissemination in rural Maryland following the retirement of HAR. The methodology included field measurements of cellular signal conditions along selected SHA-maintained corridors, real-world delivery tests using simulated travel information messages, and comparison of cellular conditions within existing HAR service areas against the weakest signal conditions associated with successful message delivery. Together, these steps provided an empirical basis for assessing whether cellular communication can support the transition from legacy radio-based communication to a layered traveler-information system.

3.1 Study Sites

The field evaluation was conducted along selected Maryland highway corridors maintained by SHA, with emphasis on rural environments where traveler-information reliability is especially important. Several urban corridors were also included to provide a comparative baseline for evaluating how cellular performance differs across roadway contexts.

As shown in **Table 5**, four test routes were selected to cover major highway corridors where traveler information plays an important operational role and where cellular coverage conditions may vary due to geography, terrain, surrounding land use, and the distribution of transportation and telecommunications infrastructure. **Figure 7** and **Figure 8** illustrate the field test routes overlaid with existing HAR locations and DMS locations respectively. Collectively, these corridors provided a basis for evaluating cellular performance under different roadway, topographic, and development conditions, as well as across areas with varying densities of DMS infrastructure, cellular network infrastructure, and existing traveler-information assets.

Table 5. Summary of Field Test Routes

Route	Area	Major Roadway
1	Western Maryland	Majorly I-68
2	Washington Metropolitan	I-495 & US-50
3 (3A&3B)	Baltimore Metropolitan & Eastern Shore (North)	US-301, I-97, I-95
4	Eastern Shore (South)	US-50 & US-13

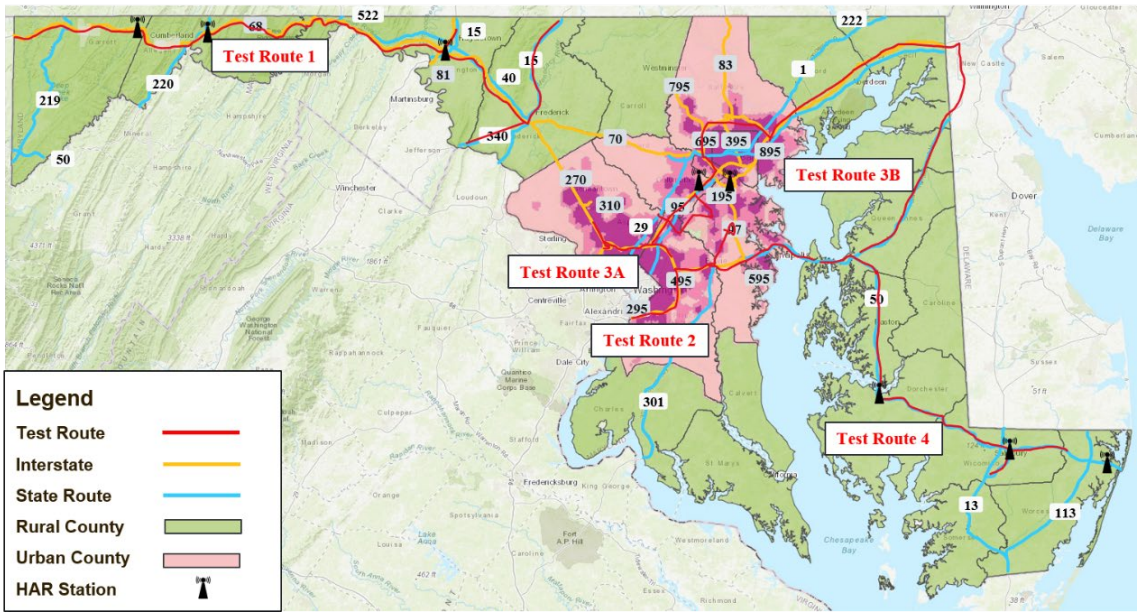


Figure 7. Test Routes and HAR Locations

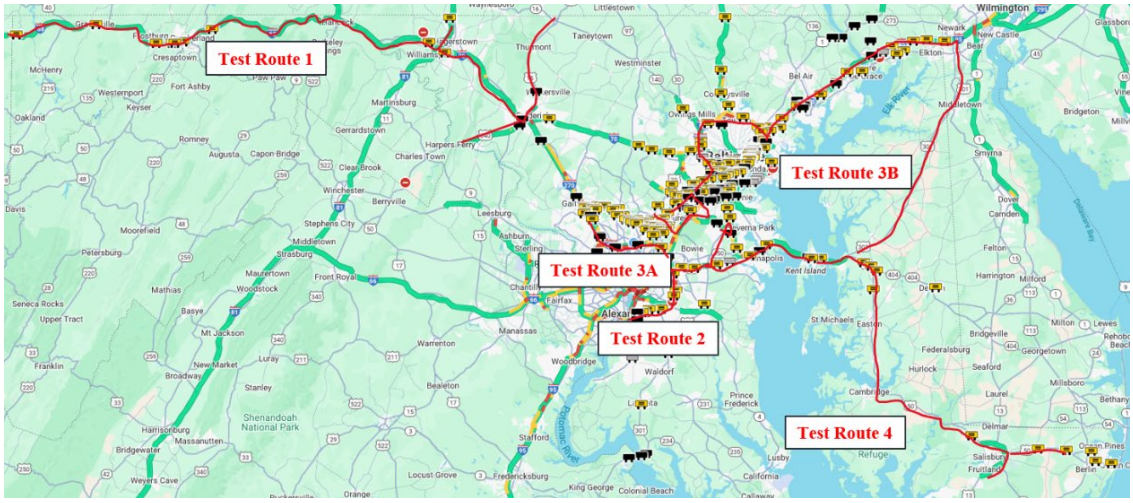


Figure 8. Test Routes and DMS Locations

3.2 Field Measurements of Cellular Signal Conditions

Field measurements of cellular signal conditions were conducted from October to November 2025 along the four selected SHA-maintained corridors. The objective was to obtain empirical measurements of cellular network performance under actual roadway operating conditions and to assess whether cellular-based traveler information can provide a reliable communication layer. Cellular signal conditions are directly relevant because SMS, app-based push notifications, 511-related digital services, and third-party navigation platforms depend on the availability and quality of the wireless connection between the traveler's device and the cellular network. Weak signal strength, poor signal quality, or low signal-to-noise conditions may reduce the likelihood of timely message delivery, increase delivery delay, or create roadway segments where mobile alerts are less dependable. Therefore, field-measured cellular signal conditions provide an empirical basis for evaluating whether cellular communication can support traveler-information dissemination along rural corridors.

The study used three standard cellular signal metrics: Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Signal-to-Noise Ratio (SNR). RSRP measures received signal strength, RSRQ characterizes signal quality under interference and network-loading conditions, and SNR indicates the clarity and decodability of the received signal.

To support quantitative comparison, the field-measured metrics were normalized and combined into a cellular reachability score. Each metric was linearly normalized, and the normalized values were integrated using a weighted geometric mean. This method was selected because cellular message delivery can be constrained by degradation in any single radio condition. The geometric mean therefore better reflects the weakest-link nature of cellular reachability than a simple arithmetic average.

$$s_{RSRP} = clip\left(\frac{RSRP + 120}{35}, 0, 1\right) \quad (1)$$

$$s_{RSRQ} = clip\left(\frac{RSRQ + 20}{10}, 0, 1\right) \quad (2)$$

$$s_{SNR} = clip\left(\frac{SNR}{20}, 0, 1\right) \quad (3)$$

where $$clip(x, 0,1) = \min(1, \max(0, x)) \quad (4)$$

$$Score = 100 \cdot (s_{RSRP}^{0.5} s_{RSRQ}^{0.2} s_{SNR}^{0.3}) \quad (5)$$

The scoring framework assigned the greatest weight to RSRP because received signal power is the primary indicator of basic coverage availability. SNR received the second-largest weight because it reflects decodability and error resilience, while RSRQ received a smaller but meaningful weight because it captures interference and cell-load effects.

Field data collection was performed using two smartphone devices: a Samsung Galaxy S25+ and an iPhone 16 Pro Max. These devices represented Android and iOS operating environments and supported cellular signal measurement across the three major wireless service providers tested in this study: AT&T, T-Mobile, and Verizon. Measurements were collected across multiple providers because cellular performance can vary substantially by carrier, corridor, and surrounding terrain.

Field measurements were collected while the test vehicle traveled under normal traffic conditions and at the posted speed limit. Established safety protocols were followed throughout the data collection process. The vehicle was operated by a designated driver, while a front-seat passenger operated and monitored the smartphone devices and measurement applications. During each field run, the applications recorded cellular signal indicators every two seconds, along with timestamps and GPS coordinates.

The GPS-referenced observations were first used to develop corridor-level cellular coverage maps. These maps visualized the spatial distribution of signal conditions along the test routes and supported the identification of roadway segments with comparatively

strong, moderate, or weak cellular coverage. The mapped signal observations were then compared with existing HAR service areas and DMS locations to assess the spatial relationship between cellular coverage and current traveler-information assets.

In addition to the map-based assessment, the cellular reachability scores were summarized statistically at the corridor level. For each route and wireless service provider, the study summarized the mean, median, 25th percentile, 75th percentile, percentage of observations below 10, and percentage of observations greater than or equal to 70. Because traveler-information reliability depends not only on average signal quality but also on weak-coverage segments, the analysis considered both central tendency and lower-tail performance. Observations below 10 were used to identify potentially unreliable cellular conditions, while observations greater than or equal to 70 indicated stronger cellular reachability along the corridor.

3.3 Real-World Traveler-Information Delivery Test

Real-world traveler-information delivery tests were conducted from April to May 2026 to complement the cellular signal measurement analysis. Although cellular signal strength and quality are important indicators of network performance, they are relative engineering measures and do not directly determine whether a traveler-information message will or will not be delivered. A weak cellular signal may still support message delivery, while stronger signal conditions may not fully represent operational reliability under all roadway conditions. Therefore, a delivery test was conducted to verify message receipt under real-world roadway conditions and to identify the approximate signal conditions under which cellular-based traveler-information messages could still be delivered.

This test used simulated traveler-information messages, rather than actual operational traveler alerts. Two cellular-based delivery methods were tested: SMS and WhatsApp. SMS was used to represent a basic one-way phone-based traveler-information delivery channel. WhatsApp was used to simulate data-network-based push notification delivery, such as notifications that could be issued through a future 511 mobile application, an agency-supported traveler-information platform, or third-party navigation applications.

Together, these two methods provided a practical basis for evaluating both text-message delivery and app-based push notification delivery over cellular networks.

The test used the same in-vehicle safety protocol as the cellular signal measurement field tests. The test vehicle traveled under normal traffic conditions and at the posted speed limit. A designated driver operated the vehicle, while a front-seat passenger monitored the smartphone devices, recorded message receipt, and documented field observations. A third research team member located remotely at the Maryland Transportation Institute (MTI) lab transmitted the simulated SMS and WhatsApp traveler-information messages at designated test points.

The delivery test focused on roadway segments associated with existing HAR service areas. Route 1 and Route 4 were included because they covered relevant HAR locations and rural corridor conditions. Route 3 was partially included, limited to Part A, because this portion was associated with HAR service-area evaluation. Route 3 Part B and Route 2 were excluded because they did not include HAR service areas relevant to the HAR retirement assessment.

Figure 9 summarizes the testing procedure. At each test location, the MTI lab sender transmitted both SMS and WhatsApp messages to the field devices. The message-sending interval was determined based on the perceived cellular infrastructure and signal environment along the corridor. In areas with relatively stable or stronger cellular conditions, messages were transmitted approximately every three minutes. In areas with weaker or more variable cellular conditions, messages were transmitted approximately every one minute to provide denser observations.

The field team recorded whether each message was received, the approximate receipt time, the roadway location, and the corresponding carrier and device information. Because repeated message transmission under real roadway conditions is operationally constrained, the resulting test points were necessarily sparser than the continuous cellular signal measurements. The delivery test therefore served as a targeted validation of message receipt rather than a continuous measurement of network performance.

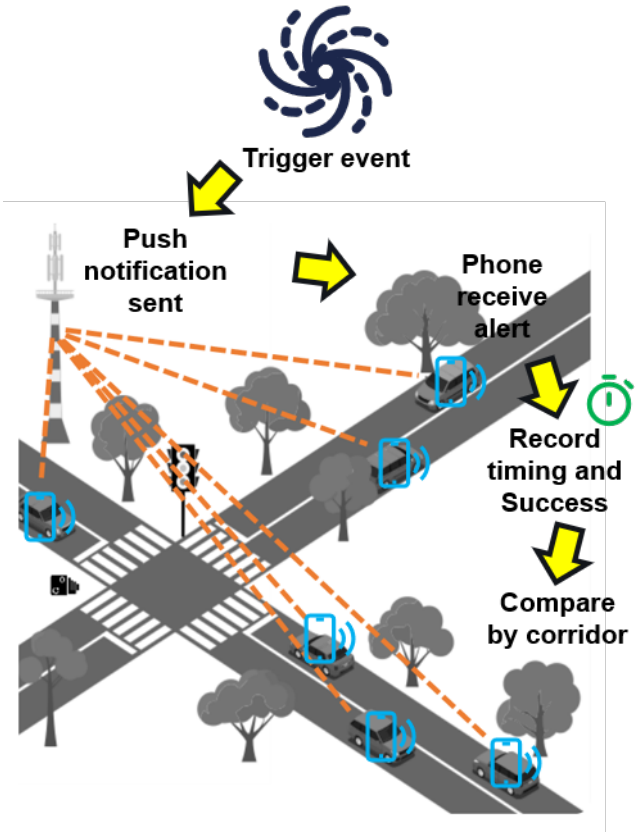


Figure 9. Procedure of the Real-World Traveler-Information Delivery Test

The evaluation considered notification delivery success, time between message trigger and message receipt, consistency across corridor segments, performance in weak-signal areas, and the ability of cellular-based messages to support incident, weather, or closure-related traveler information. However, because receipt timestamps were recorded at the minute level, the timing results should be interpreted as confirmation of same-minute delivery rather than exact delay measurement.

The delivery test results were used together with the field-measured cellular signal conditions to evaluate whether cellular-based traveler information can provide a reliable communication layer following the recommended retirement of HAR.

3.4 Assessment of Cellular Feasibility within Existing HAR Service Areas

The final step evaluated whether cellular-based traveler-information delivery could support the replacement of existing HAR service areas. This assessment combined the real-

world traveler-information delivery test with the higher-resolution cellular signal measurements.

The delivery test provided direct evidence that traveler-information messages could be received under actual roadway conditions. However, because messages could only be transmitted at discrete intervals, typically every one to three minutes depending on the perceived signal environment, the delivery test produced a relatively sparse set of message-receipt observations. By contrast, the cellular signal measurements were recorded every two seconds, providing a much denser representation of roadway cellular conditions.

To bridge the delivery-test dataset and the higher-resolution cellular signal dataset, the study used the weakest signal conditions observed during successful simulated message delivery as an empirical reference threshold, referred to as the field-test floor. The underlying assumption was that if measured cellular signal conditions at a given location were equal to or stronger than the weakest conditions under which a simulated SMS or WhatsApp message was successfully received, then cellular-based traveler-information delivery was considered feasible at that location. **Figure 10** illustrates the process used to compare high-resolution cellular signal measurements within HAR service areas against the weakest signal conditions associated with successful simulated message delivery.

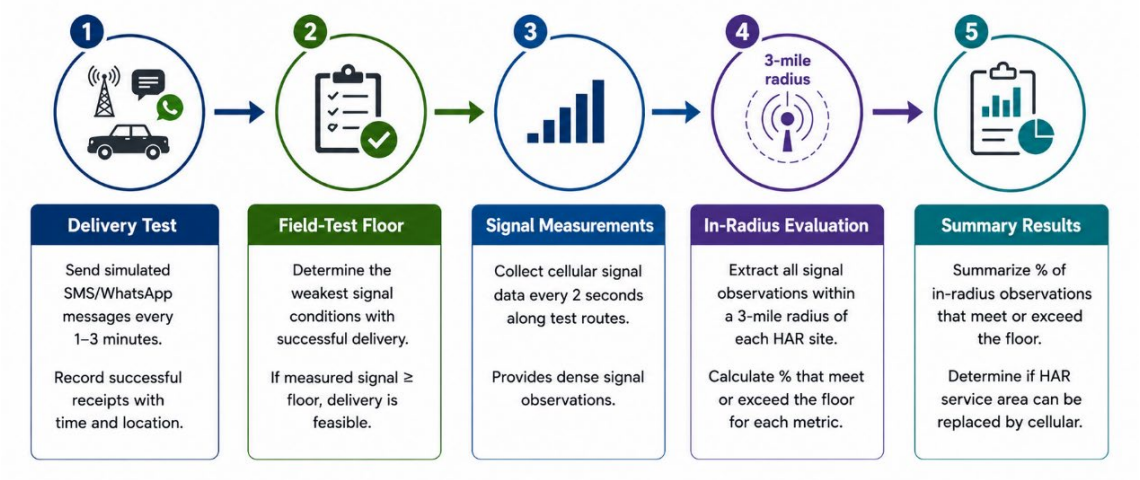


Figure 10. Evaluation Framework for Cellular Feasibility Replacing HAR

For each HAR site, cellular signal observations located within a 3-mile service radius were extracted and evaluated against the field-test floor. The analysis calculated the

percentage of in-radius observations that met or exceeded the floor for the overall reachability score, RSRP, RSRQ, and SNR. A higher percentage indicated that a larger share of the existing HAR service area had measured cellular conditions equal to or stronger than the weakest successful delivery condition observed in the field.

This approach provided an empirical basis for assessing HAR replacement feasibility. The resulting comparison was used to determine whether cellular network conditions within each HAR area were sufficient to support traveler-information dissemination after HAR retirement.

Chapter 4. Evaluation Results and Findings

4.1 Cellular Signal Conditions in Rural Maryland

The field measurements indicate that cellular signal conditions along the selected Maryland corridors varied by carrier, corridor, and geographic setting. The RSRP maps provide a spatial view of received signal strength along the tested routes and show that cellular coverage was not uniform across the study network. In general, stronger signal conditions were observed in and near the Baltimore-Washington metropolitan region and other developed corridors, while weaker or more variable conditions appeared in western Maryland, selected north-south corridor segments, and portions of the Eastern Shore.

Figure 11, **Figure 12**, and **Figure 13** present RSRP measurements for Verizon, AT&T, and T-Mobile, respectively. Verizon exhibited stronger signal conditions in portions of the Baltimore-Washington metropolitan region and the Eastern Shore, but weaker conditions were observed in western Maryland, along the Frederick-area north-south corridor, and in selected rural segments. AT&T showed greater spatial variability, with weaker conditions in western Maryland and several rural or transition areas, while stronger conditions appeared in portions of central Maryland. T-Mobile provided comparatively broad coverage across the tested corridors, including several rural highway segments, although weak or moderate signal areas remained in western Maryland and selected rural locations.

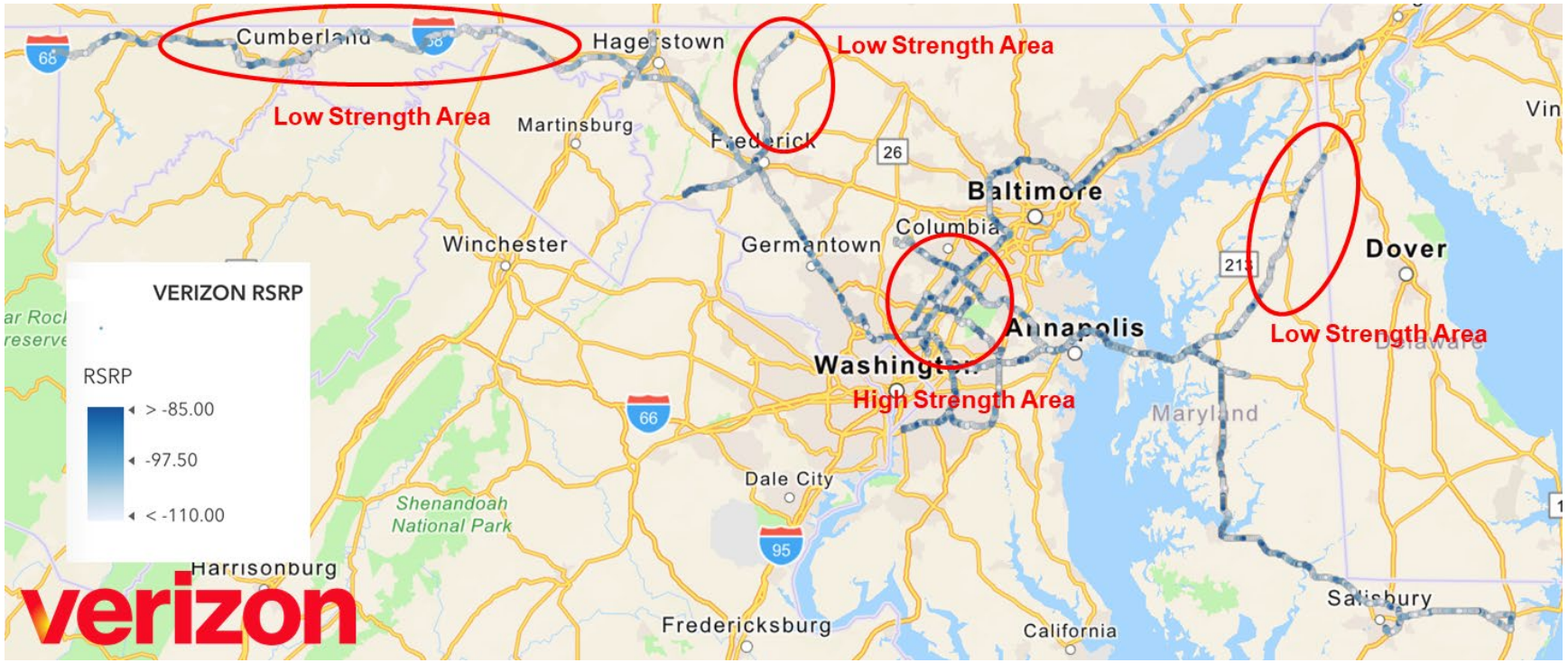


Figure 11. Verizon RSRP Measurements along the Field Test Routes



Figure 12. AT&T RSRP Measurements along the Field Test Routes

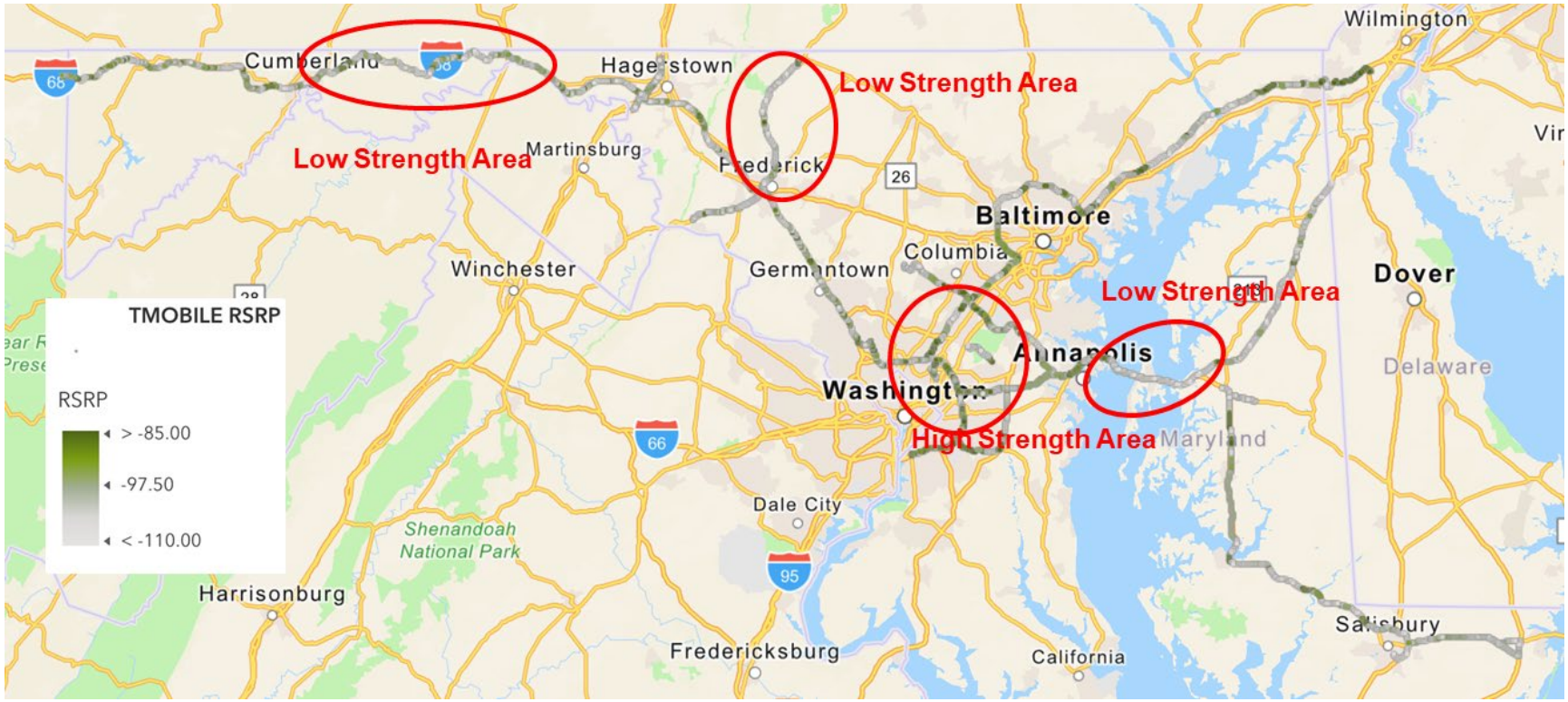


Figure 13. T-Mobile RSRP Measurements along the Field Test Routes

The corridor-level reachability statistics provide a quantitative basis for interpreting these spatial patterns. Unlike the RSRP maps, which show received signal strength only, the reachability score combines RSRP, RSRQ, and SNR into a composite measure of cellular communication conditions. For each route-carrier combination, the analysis summarized the number of observations, mean, median, 25th percentile, 75th percentile, percentage of observations below 10, and percentage of observations greater than or equal to 70. These measures were used to evaluate both typical performance and weak-signal exposure. Observations below 10 were treated as indicators of potentially unreliable cellular conditions, while observations greater than or equal to 70 indicated stronger reachability. This distinction is important because traveler-information reliability depends not only on average signal quality, but also on whether weak-coverage segments occur along the corridor.

Table 6. Cellular Reachability Score for the Test Corridors

Route	Carrier	N	Mean	Median	P25	P75	<10 (%)	≥70 (%)
1	T-Mobile	14,735	44.9	47.6	18.1	70.6	23.1	25.5
	AT&T	10,147	40.9	41.5	23.6	60.9	19.4	18.3
	Verizon	12,967	19.8	0.0	0.0	41.5	57.0	4.3
2	T-Mobile	11,502	44.2	45.2	19.1	70.9	22.3	27.1
	AT&T	6,117	16.0	0.0	0.0	27.0	66.2	3.3
	Verizon	12,615	48.4	52.3	21.6	76.1	21.0	31.2
3	T-Mobile	5,328	57.4	61.3	41.9	79.6	12.7	37.9
	AT&T	6,206	37.9	41.4	0.0	66.2	37.2	21.5
	Verizon	6,622	53.9	59.8	28.6	82.7	19.1	39.6
4	T-Mobile	15,677	46.1	52.6	19.5	69.5	23.3	21.6
	AT&T	11,609	37.6	37.8	0.0	62.1	31.0	19.0
	Verizon	14,951	44.0	44.1	0.0	73.2	26.0	27.3

Table 6 summarizes corridor-level cellular reachability scores by route and carrier. The statistical results indicate that T-Mobile was the most consistent provider across the tested corridors, with mean reachability scores ranging from 44.2 to 57.4 and moderate-to-strong median scores on all four routes. T-Mobile also showed the strongest Route 3 performance, with a mean score of 57.4, a median score of 61.3, and the lowest share of

observations below 10 for that route. Verizon performed well on Routes 2, 3, and 4, with mean scores of 48.4, 53.9, and 44.0, respectively; however, it showed substantial weakness on Route 1, where the mean score was 19.8, the median was 0.0, and 57.0 percent of observations were below 10. AT&T showed moderate performance on Route 1, with a mean score of 40.9 and a median score of 41.5, but weaker lower-tail performance on Routes 2, 3, and 4. Its Route 2 performance was the weakest, with a mean score of 16.0 and 66.2 percent of observations below 10.

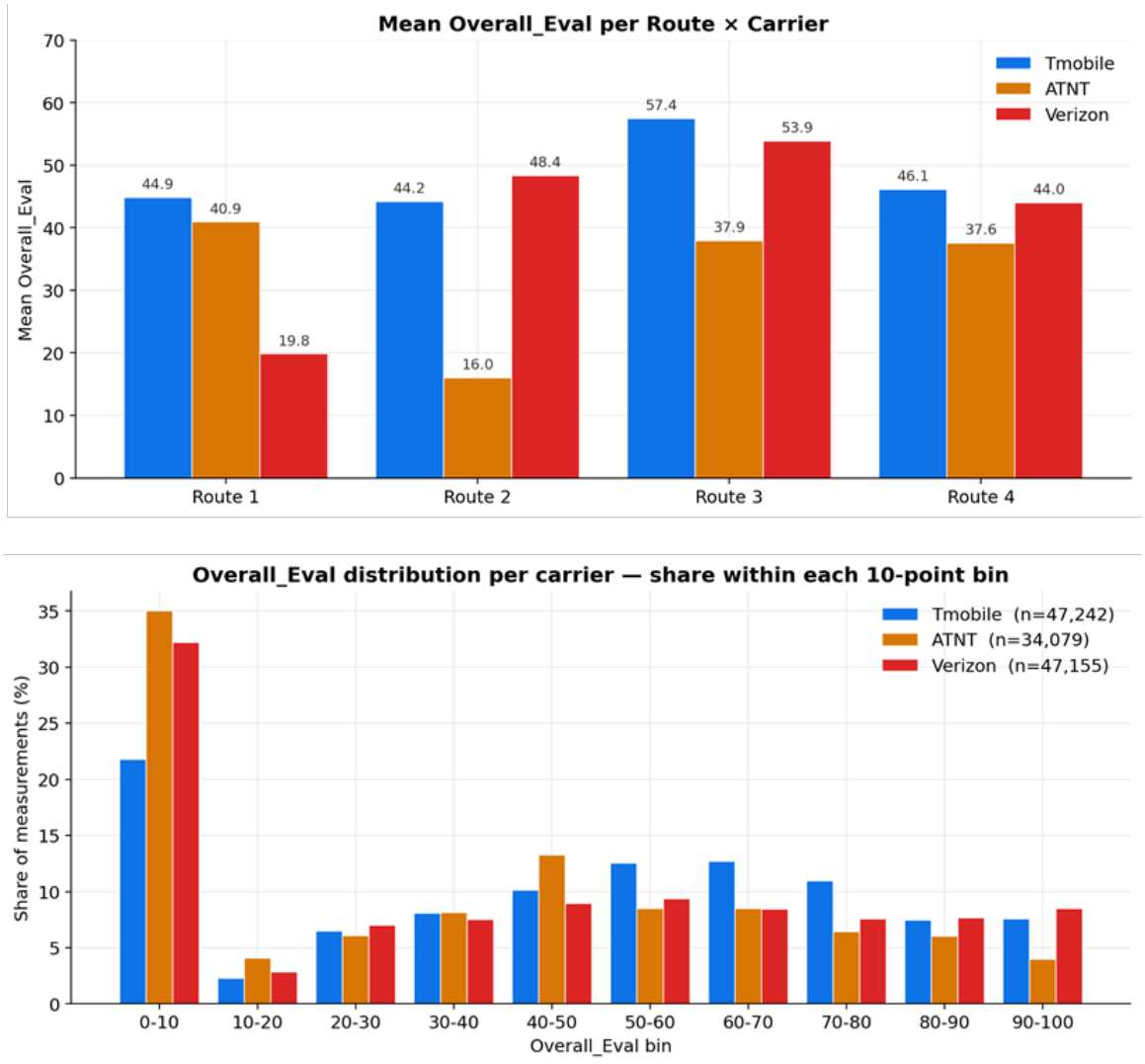


Figure 14. Mean and Distribution of Cellular Reachability Score by Carrier

As shown in **Figure 14**, the route-level means and overall score distribution confirm the same pattern observed in **Table 6**. T-Mobile had the most stable performance across

corridors, while Verizon and AT&T showed stronger corridor-specific variation. The distribution plot also shows that AT&T and Verizon had larger shares of observations in the lowest score bin than T-Mobile. This lower-tail performance is important because weak-score segments may represent locations where cellular-based traveler-information delivery is less dependable.

Hence, the map-based and statistical results show that cellular reliability is strongly influenced by carrier network deployment, corridor location, and local geography. Cellular coverage is sufficiently widespread to support a major traveler-information role, but performance is not uniform across providers or roadway environments.

4.2 Results for Real-World Traveler-Information Delivery Test

As shown in **Figure 15**, the delivery test included **148 roadway locations** along the selected corridors. The results indicate strong initial feasibility for cellular-based traveler-information dissemination. Both SMS and WhatsApp messages were successfully received in all recorded tests across the AT&T, T-Mobile, and Verizon devices. The received timestamps matched the trigger minute for all messages, confirming **same-minute delivery** during the field test. Accordingly, the observed delivery success rate was **100 percent** for the tested carriers and message types.

The weak-signal examples provide an important interpretation of the reachability score. The score is a conservative screening metric designed to identify locations with degraded cellular conditions; it is not a binary predictor of message delivery success or failure. Because the score is based on normalized RSRP, RSRQ, and SNR values, a very weak value in one component can reduce the composite score to zero. Therefore, a zero score should be interpreted as an indicator of elevated delivery risk, not as evidence that message delivery cannot occur.

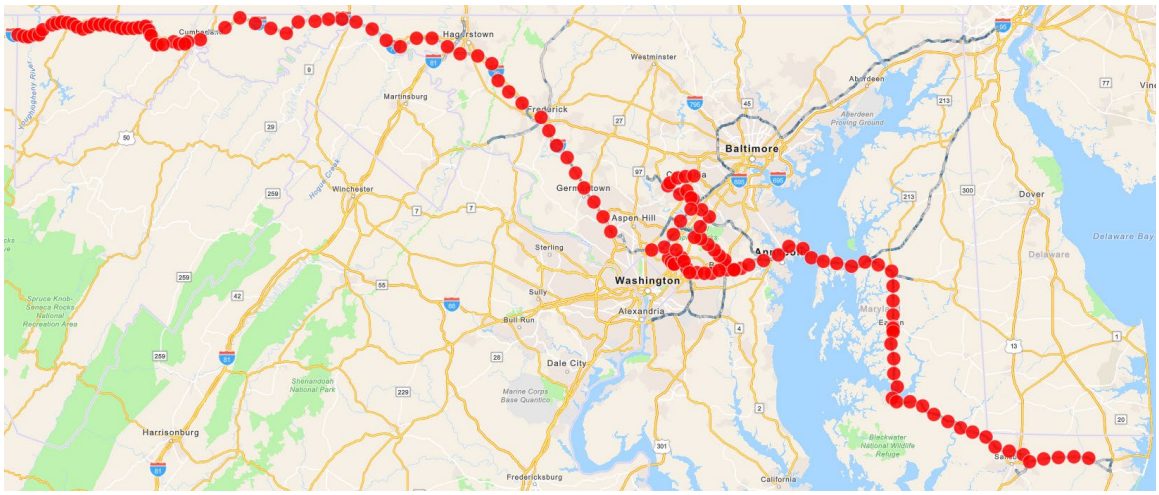


Figure 15. Locations for the Real-World Traveler-Information Delivery Test

As shown in **Table 7**, several AT&T observations on Route 3 had very weak measured signal conditions and an overall reachability score of zero. Nevertheless, both WhatsApp and SMS messages were received within the recorded minute at these locations. This result confirms that weak signal conditions do not necessarily prevent message delivery. At the same time, these locations remain important because they identify the lower boundary of observed successful delivery in the field test. For this reason, the weak-signal delivery observations were used to support the development of the field-test floor for the subsequent HAR service-area feasibility assessment.

Using delivery-test records, the field-test floor was defined as the weakest observed cellular signal conditions under which simulated traveler-information messages were successfully received. Each delivery-test point was matched to the closest cellular signal measurement within 30 meters for each carrier. Based on all 148 successful April-May delivery points, the final field-test floor was established as **Reachability Score ≥ 0, RSRP ≥ -120 dBm, RSRQ ≥ -17 dB, and SNR ≥ -7.3 dB**.

Table 7. Successful Message Delivery under Weak AT&T Signal Conditions

Latitude	Longitude	Route	RSRP	RSRQ	SNR	Score	WhatsApp	SMS
38.9855	-76.7175	3	-107	-12	-5.3	0	Yes	Yes
38.99692	-76.7405	3	-113	-16	-5.3	0	Yes	Yes
39.0154	-76.7594	3	-105	-13	-5.3	0	Yes	Yes
39.03109	-76.7829	3	-88	-16	-5.3	0	Yes	Yes
39.04835	-76.812	3	-107	-8	-5.3	0	Yes	Yes
39.05282	-76.837	3	-111	-14	-5.3	0	Yes	Yes
39.08603	-76.8126	3	-112	-13	-5.3	0	Yes	Yes

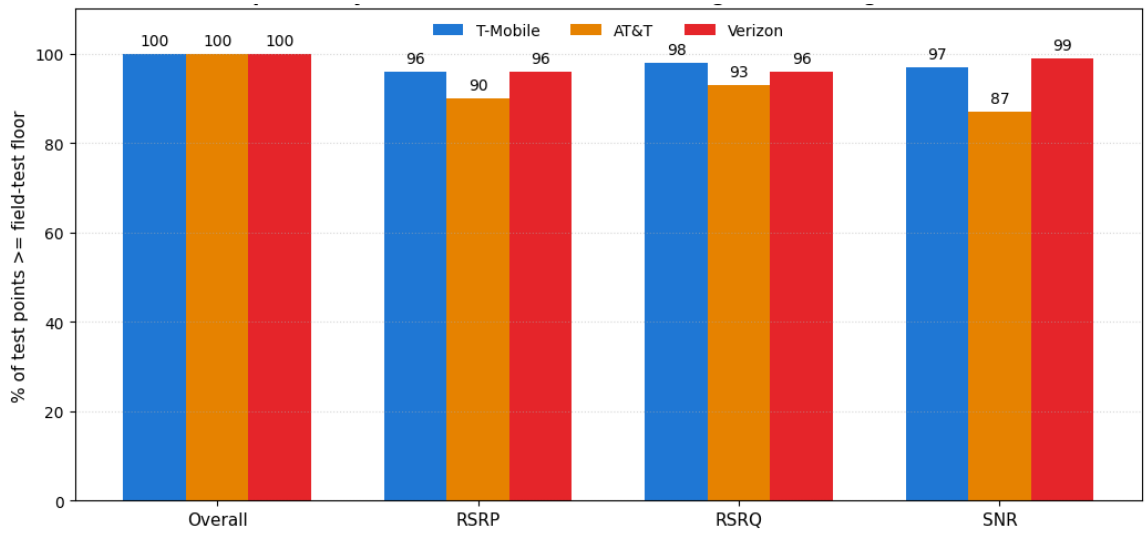


Figure 16. Field-Test Floor by Carrier and Signal Metric

As shown in **Figure 16**, all carriers met or exceeded the reachability score floor at all successful delivery-test points. For the individual signal metrics, most combined test points also met or exceeded the final floor. These results indicate that the final field-test floor is a conservative empirical threshold derived from successful message delivery under real roadway conditions. It does not represent a universal engineering minimum for cellular communication. Rather, it provides a benchmark for evaluating whether measured cellular conditions within HAR service areas are at least as strong as the weakest conditions under which simulated traveler-information messages were observed to be delivered successfully.

4.3 Cellular Feasibility within Existing HAR Service Areas

Figure 17 shows the HAR station locations and their approximate 3-mile and 5-mile service areas. **Table 8** compares cellular signal conditions within each 3-mile HAR service area against the field-test floor. The results show that cellular conditions within the HAR service areas were generally at or above the weakest signal conditions associated with successful simulated message delivery. All nine HAR sites met the reachability floor for 100 percent of in-radius observations. For RSRP, which reflects received signal strength, all sites showed strong performance, with at least 92.7 percent of observations meeting or exceeding the floor. This indicates that basic cellular coverage was broadly available within the evaluated HAR service areas.

RSRQ results were also consistently strong. Eight of the nine HAR sites had at least 90 percent of observations meeting or exceeding the RSRQ floor, and HAR-8 was only slightly below that threshold at 89.5 percent. This suggests that signal quality was generally sufficient within the HAR service areas. SNR showed the greatest variation, with lower shares at HAR-1, HAR-8, and HAR-9. However, these lower SNR values should be interpreted in context. HAR-1, HAR-8, and HAR-9 are located in urban areas where DMS coverage, MD 511 access, roadway infrastructure density, and cellular network redundancy are generally stronger than in remote rural corridors. Therefore, lower SNR percentages at these locations do not indicate the same level of traveler-information risk that similar values would represent in isolated rural areas.

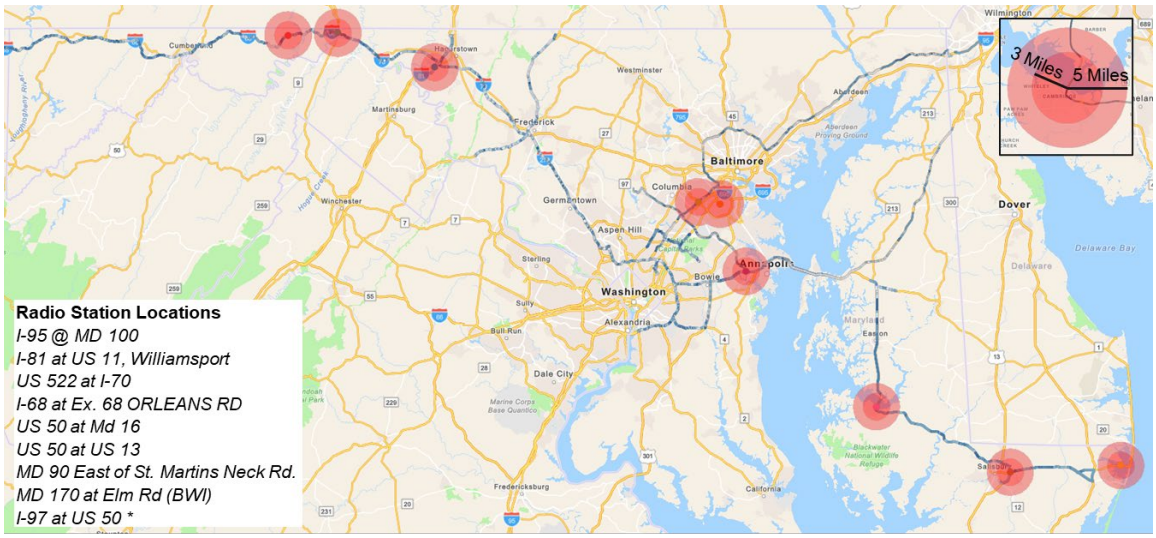


Figure 17. HAR Station Locations and Approximate Service Areas

Table 8. Cellular Signal Conditions within HAR Service Areas Compared with the Field-Test Floor

HAR	Site	N	Score ≥ 0	RSRP ≥ 120 dBm	RSRQ ≥ 17 dB	SNR ≥ 7.3 dB
HAR-1	I-95 @ MD 100	876	100.0%	100.0%	94.4%	66.4%
HAR-2	I-81 @ US 11, Williamsport	2,443	100.0%	99.5%	90.1%	99.6%
HAR-3	US 522 @ I-70 (Hancock)	928	100.0%	100.0%	99.8%	100.0%
HAR-4	I-68 @ Ex. 68 Orleans Rd	410	100.0%	92.7%	99.5%	97.1%
HAR-5	US 50 @ MD 16	312	100.0%	99.7%	91.7%	95.2%
HAR-6	US 50 @ US 13 (Salisbury)	1,246	100.0%	96.9%	97.5%	97.8%
HAR-7	MD 90 E of St. Martins Neck Rd	405	100.0%	98.8%	100.0%	100.0%
HAR-8	MD 170 @ Elm Rd (BWI)	401	100.0%	100.0%	89.5%	60.8%
HAR-9	I-97 @ US 50 (Annapolis)	4,218	100.0%	99.0%	96.4%	84.5%

Note: The any-carrier percentage represents the combined share of in-radius observations meeting or exceeding the field-test floor across T-Mobile, AT&T, and Verizon. **Green** indicates values of 90 percent or higher, **amber** indicates values from 70 to 90 percent, and **red** indicates values below 70 percent.

The rural HAR sites showed stronger feasibility for cellular-based replacement. HAR-2, HAR-3, HAR-4, HAR-5, HAR-6, and HAR-7 generally met or exceeded the field-test floor across the key metrics, with RSRP, RSRQ, and SNR values mostly above 90 percent. These locations are more relevant to the central question of rural HAR replacement because they represent the types of corridors where HAR historically provided supplemental

traveler information. The high percentage of in-radius observations meeting the floor at these sites indicates that cellular-based delivery is technically feasible within the existing rural HAR service areas evaluated in this study.

Figure 18 provides a distributional view of the in-radius cellular signal observations for each HAR site. The boxplots compare the distribution of reachability score, RSRP, RSRQ, and SNR against the field-test floor. The distributions show that median RSRP values were above the floor across all HAR sites, RSRQ values were generally above the floor, and SNR medians were also above the floor for each site. Although lower-tail values were present at some locations, the overall pattern indicates that cellular conditions within the HAR service areas were generally sufficient relative to the empirically observed message-delivery threshold.

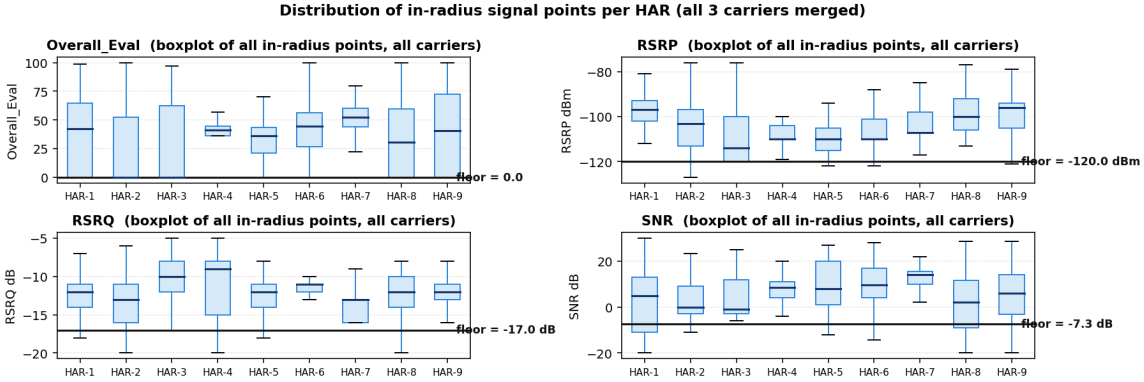


Figure 18. Distribution of In-Radius Cellular Signal Observations by HAR Service Area

The HAR feasibility assessment was based on nine HAR sites located along or within the selected field-test corridors for which sufficient GPS-referenced cellular measurements were available within the defined 3-mile analysis radius. While these sites represent the HAR locations directly covered by the project's field data, the findings are expected to be generally applicable to other HAR installations with similar roadway, coverage, and operating conditions.

In summary, the results indicate that cellular-based traveler-information delivery can support the replacement of HAR as a routine traveler-information channel. The cellular measurements within existing HAR areas generally met or exceeded the field-test floor

derived from successful real-world message delivery. This finding supports HAR retirement, provided that cellular-based delivery is implemented as part of a layered communication system that continues to use DMS, CHART/MD 511, WEA/IPAWS, third-party navigation platforms, and corridor-level monitoring to maintain redundancy and roadside visibility where needed.

4.4 Discussion

The spatial comparison of cellular coverage and DMS locations shows how traveler information can be supported in a post-HAR environment. Cellular coverage generally follows the roadway network and provides broad corridor-level communication, while DMS infrastructure is concentrated in the Baltimore-Washington region and along major highway corridors where traffic volumes, decision points, and operational needs are highest.

Figure 19 illustrates the spatial relationship between field-measured cellular conditions and existing DMS locations. This distinction is important to the post-HAR communication strategy. Cellular communication can serve as the primary traveler-information delivery pathway beyond fixed roadside assets, while DMS remains essential for direct, location-specific, and glance-readable messages at key decision points. In the absence of HAR, cellular delivery and DMS should operate as complementary layers: cellular communication extends reach across corridors, and DMS provides roadside visibility, confirmation, and redundancy where traveler decisions are most time-sensitive.

Figure 20 illustrates the overlap among HAR service areas, DMS locations, and cellular coverage across Maryland. The combined spatial comparison further supports a layered replacement strategy. In rural Maryland, HAR and DMS assets appear in localized clusters, while cellular coverage provides broader corridor-based support. In the Baltimore-Washington region, higher DMS density and stronger cellular availability create greater multichannel overlap. This pattern indicates that cellular communication can replace the routine HAR function across a broader roadway footprint, while DMS strengthens the post-HAR system by providing independent roadside visibility and operational redundancy.

Overall, the spatial evidence indicates that DMS should remain a central component

of Maryland's traveler-information system after HAR retirement. Cellular communication can support the replacement of HAR as a routine dissemination channel, but DMS strengthens the post-HAR system by providing direct roadside visibility, supporting decision-point messaging, and adding redundancy in areas where cellular performance may vary.

The appropriate combination of communication technologies should also vary by operational scenario and available infrastructure. The field results support cellular-based delivery as a broad communication layer, while DMS should be prioritized where direct roadside visibility is most valuable. Supporting channels should then be added according to the urgency, spatial extent, and operational characteristics of the event. Importantly, DMS provides a roadside display function but may itself depend on fiber, cellular, microwave, or other backhaul for remote operation; therefore, both traveler-facing coverage and communications backhaul should be considered when evaluating redundancy.

Operationally, the layered system should use a common verified source of traveler information so that the same underlying event information is distributed across channels. For routine incidents, closures, work zones, and weather conditions, the CHART Statewide Operations Center can continue to serve as the primary source for verified traveler information, with information disseminated through appropriate DMS, cellular/digital services, and third-party navigation platforms. When an event reaches an established life-safety threshold, authorized alerting authorities can add WEA through the IPAWS. Messages distributed through different channels should remain consistent in the underlying event, location, recommended action, and status, while being adapted to the length and presentation requirements of each channel. Escalation should therefore be event-based rather than technology-based. Routine events may use MD 511, navigation platforms, and selected DMS; events requiring immediate corridor-level action may use these channels simultaneously; and life-safety events may additionally trigger WEA/IPAWS. This approach allows the number of active communication layers to increase with event severity while maintaining a consistent source of verified information.

Table 9. Traveler Information Channel Prioritization by Scenarios

Scenario	**Primary Channels**	**Operational Priority**
Routine Rural Corridors	Cellular + targeted DMS/portable DMS	Broad digital dissemination with DMS at major decision points; Prioritize redundancy where cellular measurements show weak or variable conditions
Evacuation corridors	Cellular + DMS + WEA/IPAWS when life-safety thresholds are met	Provide consistent evacuation information across multiple channels
Localized hazards (Flash-flood/high-tide locations/low-clearance bridges)	Geofenced cellular alerts + nearby DMS where practical + WEA/IPAWS for severe life-safety events	Target travelers approaching a geographically defined hazard; Deliver location-specific warnings before the decision point

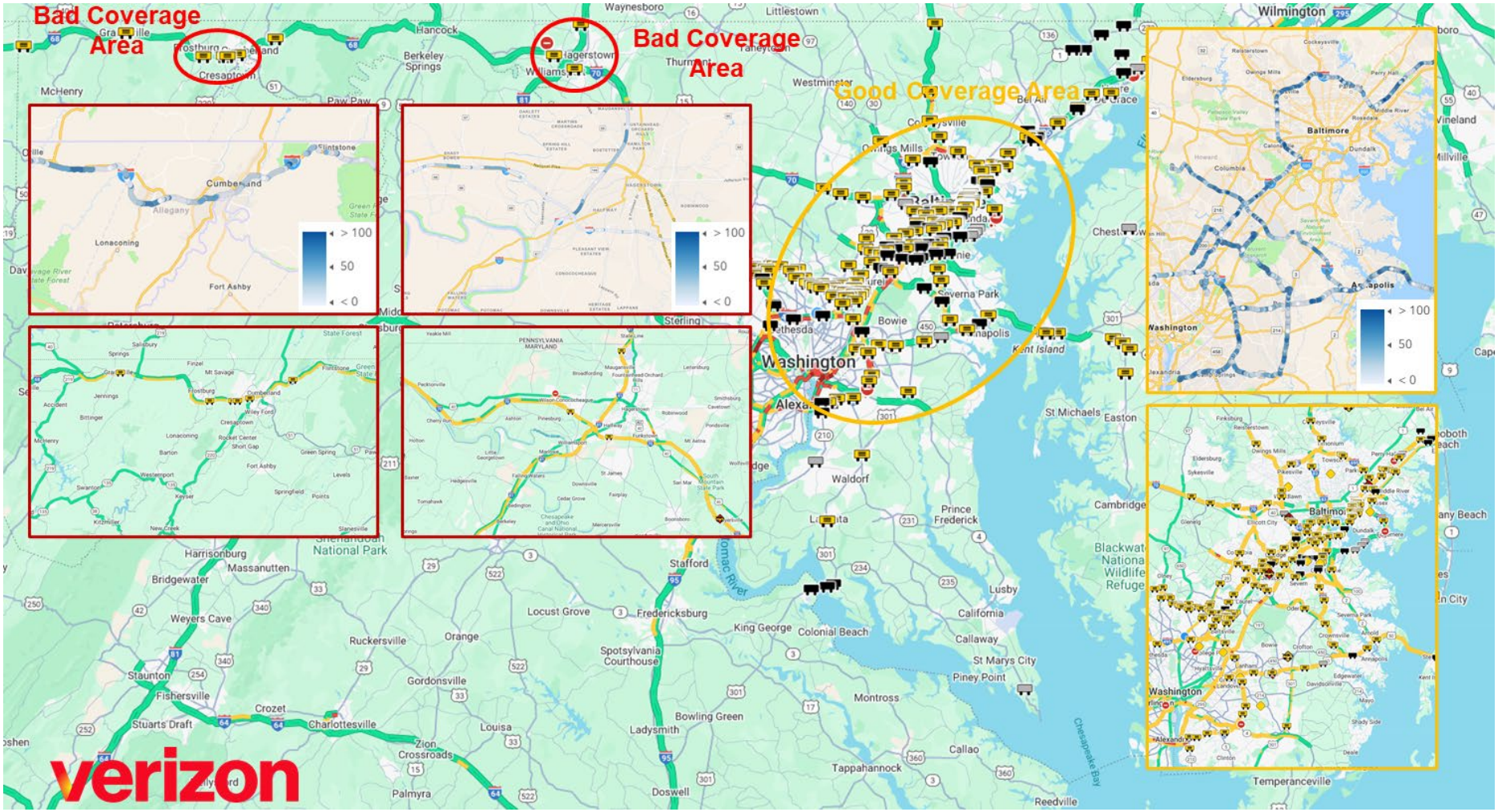


Figure 19. Cellular Signal Conditions versus DMS Deployment (Verizon as an Example)

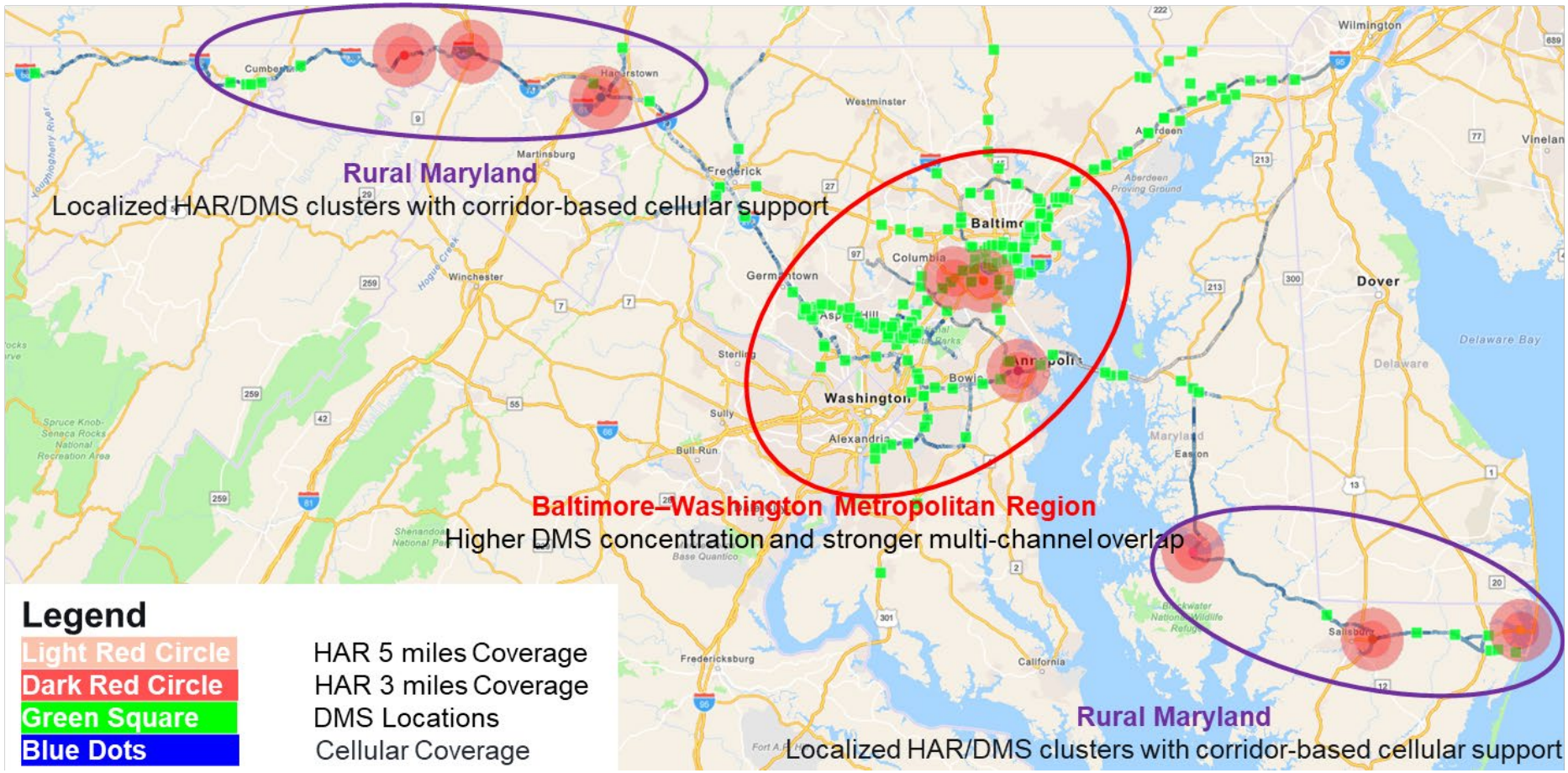


Figure 20. Spatial Distribution of Communication Channels in Maryland

4.5 Implementation Recommendations

Based on the review and field experiments, this project recommends that SHA retire HAR as a routine traveler-information dissemination channel. The recommended implementation direction is not a one-to-one replacement of HAR with a single technology, but a transition to a layered traveler-information system in which cellular-based delivery serves as the primary replacement pathway and DMS remain a core roadside communication asset.

The technical basis for this recommendation is supported by the project's field results, which demonstrated sufficient feasibility for cellular-based traveler information across the tested corridors and within existing HAR service areas. Field measurements showed that cellular coverage generally extends along the roadway network more broadly than the localized HAR footprint. Real-world delivery testing confirmed successful receipt of all simulated SMS and WhatsApp messages across the tested carriers and roadway conditions. In addition, the HAR service-area assessment showed the rural HAR service areas evaluated generally had more than 90 percent of observations meeting or exceeding the field-test floor across the principal signal metrics, including reachability scores. This indicate that measured cellular conditions within existing HAR areas were generally at or above the weakest signal conditions associated with successful message delivery. Collectively, these findings indicate that cellular communication can support the routine traveler-information function historically served by HAR and support transitioning the evaluated HAR locations away from routine HAR operation while retaining multiple traveler-information channels.

Implementation should proceed in phases consistent with the roadmap. In the short term, SHA should inventory existing HAR assets and related DMS backhaul dependencies and establish a formal decommissioning plan that addresses equipment disposition, administrative and licensing requirements, messaging procedures, and public communication. In the medium term, HAR equipment should be retired or repurposed where replacement capability has been confirmed, associated signage should be removed or modified as appropriate, and targeted improvements should be made in locations where cellular coverage or roadside communication remains limited. Over the longer term, SHA should periodically reassess cellular coverage and traveler-information system performance and evaluate emerging technologies for incorporation

when they provide demonstrated operational value. Throughout the transition, existing DMS, MD 511, WEA/IPAWS, and navigation-platform capabilities should be maintained to preserve redundancy and provide travelers with multiple means of receiving official information.

Overall, the recommended implementation action is to retire HAR and replace its routine communication function with a cellular-centered, DMS-supported, multichannel traveler-information system. This approach reflects current traveler behavior, aligns with national practice, reduces reliance on obsolete radio infrastructure, and preserves operational redundancy through modern digital and roadside communication channels.

Chapter 5. Conclusion

This study evaluated strategies for improving traveler-information dissemination in rural Maryland, with particular attention to aging Highway Advisory Radio (HAR) infrastructure, limited rural roadside communication coverage, and variable cellular connectivity. The project was designed to assess whether modern communication approaches can provide reliable, scalable, and operationally sustainable support for traveler information in rural and emergency-sensitive corridors.

The review of existing technologies and current practices showed that traveler information is increasingly delivered through a layered system that includes Dynamic Message Signs (DMS), 511 platforms, cellular-based services, navigation applications, Wireless Emergency Alerts, and other targeted communication tools. National practice also indicates a clear shift away from routine HAR use as agencies retire or narrow legacy radio systems and rely more heavily on digital, roadside, and emergency alerting channels. The review identified commercial cellular communication and DMS as mature technologies available for near-term implementation, while technologies such as Vehicle-to-Everything (V2X) and satellite-based communication require further evaluation before they can be considered for broader deployment in rural Maryland.

The field evaluation provided the project-specific basis for assessing cellular communication in Maryland. Cellular performance varied by carrier, corridor, and geographic setting, confirming that no single cellular provider can be assumed to provide uniform performance across all rural roadway environments. At the same time, cellular coverage generally extended along the roadway network, all simulated Short Message Service (SMS) and app-based messages were successfully received under the tested roadway conditions, and cellular conditions within the evaluated rural HAR service areas generally met or exceeded the weakest conditions associated with successful message delivery, including reachability scores. These findings support the use of cellular-based communication as the primary pathway for routine traveler-information delivery in the evaluated areas.

The observed carrier and geographic variability also demonstrates why cellular communication should not be implemented as a standalone solution. DMS should

remain a core component of the system because it provides direct, location-specific, glance-readable information at important decision points without requiring travelers to use a personal mobile device. However, DMS roadside visibility should be distinguished from its communications backhaul, because individual signs may depend on fiber, cellular, microwave, or other communications connections for remote operation. Existing SHA channels, including MD 511 and Wireless Emergency Alerts (WEA) issued through the Integrated Public Alert and Warning System (IPAWS), should therefore continue to provide complementary dissemination pathways and operational redundancy.

Based on the field results, SHA should retire HAR as a routine traveler-information channel where replacement capability has been confirmed. HAR locations not directly represented in the field evaluation should first be assessed using comparable cellular measurements and delivery criteria before site-specific retirement decisions are made. Once replacement capability is confirmed, implementation should proceed through a formal decommissioning process addressing equipment disposition, licensing, signage, and public communication, while maintaining DMS and existing digital channels as complementary components of the traveler-information system.

Following implementation SHA should periodically evaluate the performance of the layered traveler-information system using measurable indicators. Key measures should include message delivery success rate, delivery time, geographic coverage, system availability, and the availability of an alternative communication channel when the primary channel is unavailable. The field test results provide an initial project baseline against which future monitoring can be compared.

Based on these findings, this study recommends that SHA retire HAR as a routine traveler-information dissemination channel and transition to a cellular-centered, DMS-supported communication system. This approach reflects current traveler behavior, reduces reliance on obsolete infrastructure, and supports a more modern, scalable, and resilient traveler-information system for rural Maryland. Implementation should be accompanied by periodic performance monitoring to ensure that rural traveler-information coverage and redundancy are maintained over time.

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