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working to advance road weather information systems technology

An Intelligent Human-Centric Communication System for Adverse Weather and Road Conditions

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Aurora Project 2023-02

Final Report
September 2025

About Aurora

The Aurora program is a partnership of highway agencies that collaborate on research, development, and deployment of road weather information to improve the efficiency, safety, and reliability of surface transportation. The program is administered by the Center for Weather Impacts on Mobility and Safety (CWIMS), which is housed under the Institute for Transportation at Iowa State University. The mission of Aurora and its members is to seek to implement advanced road weather information systems (RWIS) that fully integrate state-of-the-art roadway and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures.

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16. Abstract

Adverse weather conditions present significant risks to motorists, making safe navigation challenging. Artificial intelligence (AI) advancements have facilitated the development of intelligent systems to address these concerns. This project introduces Conversational AI for Road Weather Information Systems (CARWIS), an AI-powered solution that provides real-time data on road conditions during severe weather. CARWIS gathers data from various sources, including weather forecasts and traffic cameras, and employs natural language processing to generate timely and accurate insights into road conditions. CARWIS can detect hazardous conditions, such as icy roads or low visibility due to fog or precipitation, and refine its predictions over time, enabling drivers to make informed decisions about their travel plans, potentially reducing accidents and enhancing safety. Additionally, CARWIS can assist transportation professionals in planning for and responding to severe weather events by providing detailed information on road conditions. This enables officials to prioritize resources and make well-informed decisions regarding road closures and safety measures. This innovative solution harnesses the power of AI to improve road safety and reduce incidents during adverse weather conditions. As AI technology continues to progress, it is anticipated that more advanced systems will be developed to assist in navigating and managing severe weather events on roadways.

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AN INTELLIGENT HUMAN-CENTRIC COMMUNICATION SYSTEM FOR ADVERSE WEATHER AND ROAD CONDITIONS

Final Report
September 2025

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EXECUTIVE SUMMARY

The Conversational AI for Road Weather Information Systems (CARWIS) Drive Assist project is an advanced, artificial intelligence (AI)-powered web application developed by the University of Iowa Hydroinformatics Lab to enhance road safety and travel planning across Iowa. Using real-time data from the Iowa Department of Transportation (DOT), the National Weather Service, and other authoritative sources, the system provides drivers with up-to-date information on road conditions, weather hazards, traffic incidents, and more.

The platform has a modern, user-friendly interface, allowing users to interact with four specialized AI experts: Drive Assistant, Winter Expert, Live View Expert, and 511 Data Expert. Each expert is tailored to address specific travel scenarios, from general driving conditions to winter-specific conditions and comprehensive report generation. The backend architecture, powered by Node.js, integrates multiple data sources and OpenAI's latest model (GPT-4.1) to respond to natural language user queries. Nginx serves as a reverse proxy web server that efficiently routes incoming requests to the appropriate backend services.

The core strength of CARWIS lies in its ability to merge live sensor data, traffic camera imagery, and AI-driven reasoning to support informed, proactive decision-making by travelers and agency users alike. In a structured field evaluation conducted with DOT professionals, users consistently found the system easy to use, contextually relevant, and potentially valuable for operational integration. Feedback from this evaluation is helping to guide future development efforts focused on improving response speed and providing concise, action-oriented summaries.

INTRODUCTION

Problem Statement

Despite ongoing improvements to Iowa's transportation infrastructure and information systems, significant challenges remain in delivering timely, comprehensive, and user-friendly road safety information to drivers—especially during adverse winter weather conditions (Alabbad et al. 2023, 2024). Winter hazards such as snowfall, ice, and low visibility pose a substantial threat to driver safety and performance, with statistics indicating a dramatic increase in crash rates during snowstorms and thousands of weather-related fatalities and injuries nationwide each year (Roadway Safety Foundation 2022). These conditions not only endanger lives but also impede drivers' ability to effectively anticipate and respond to changing road environments, a problem particularly acute in snow belt states like Iowa.

The Iowa Department of Transportation (DOT) provides many valuable resources, including the 511 system, which offers statewide updates on highway conditions, closures, and camera feeds. However, the current system exhibits important limitations. Coverage is primarily focused on Interstates, US routes, and state highways, leaving county and local roads underrepresented and drivers with incomplete situational awareness (Sharma et al. 2015). In practice, many drivers supplement 511's offerings with other sources—such as weather apps, local news, and direct communication with county agencies—to obtain information that ideally would be immediately accessible.

This fragmentation complicates decision-making, as reflected in user behavior; nearly 60% of surveyed Iowans relied on external sources like television, radio, or third-party apps for weather-related travel updates despite the existence of 511, while nearly half opted for alternatives like Google Maps or in-car navigation for traffic and travel-time insights, often citing greater usability (Sharma et al. 2015). More recent national-level studies confirm that smartphone navigation apps such as Google Maps and Waze now dominate traveler information use (Guin et al. 2021). These patterns reveal two key issues: drivers face cognitive overload from navigating disparate information sources, and they gravitate toward tools that are more intuitive and accessible. Furthermore, user feedback indicates a strong demand for higher-quality, integrated camera images and real-time data to facilitate safer, more confident decision-making (Sharma et al. 2015).

Another critical underlying factor in these challenges is the limited availability of real-time, actionable information tailored to the needs of drivers, particularly during hazardous weather events (Androutsopoulou et al. 2019). Existing methods of information delivery often lack the user-friendliness, immediacy, and customization required for optimal driver decision-making, and the transformative potential of emerging intelligent and interactive technologies has not yet been fully realized (Shah et al. 2019, Yesilkoy et al. 2024a).

To address these urgent gaps, Conversational AI for Road Weather and Information Systems CARWIS) seeks to leverage the latest advancements in artificial intelligence (AI) and web technology. By building upon existing Iowa DOT data and services, CARWIS aims to significantly enhance the accessibility, usability, and relevance of road weather information. The solution provides a single, integrated platform with an AI-powered conversational interface, enabling users to interact with specialized virtual assistants and receive real-time, expert guidance on driving conditions. This innovative approach has the potential to empower drivers with the information they need, when and how they need it, ultimately improving safety and reducing risks during winter weather and beyond. The system integrates technological innovation with a deep understanding of human factors, ensuring that information delivery aligns with the real-world needs and behaviors of Iowa's diverse driver population.

Organization of Report

The rest of the report is divided into chapters as follows:

- **Background** provides context on the motivation for developing CARWIS, including existing challenges in road weather information systems (RWIS).
- **Project Objectives** summarizes the goals of the project and the key aspects of the development process.
- **CARWIS System Design** details the architecture of the platform, including frontend components, backend infrastructure, data processing functions, and the roles of each AI expert.
- **Data Sources** outlines the official Iowa DOT application programming interfaces (APIs) integrated into the system, such as RWIS and Iowa 511 APIs.
- **Evaluation** presents the results of a structured user study involving DOT professionals, including both quantitative feedback and qualitative insights to assess usability, relevance, and opportunities for future enhancement.

BACKGROUND

This chapter provides a comprehensive review of the existing landscape of road safety, traveler information systems, and the transformative role of artificial intelligence in intelligent transportation. It establishes the critical need for advanced solutions like CARWIS by detailing current challenges and contextualizing the project within the broader academic and practical advancements in the field.

The Imperative for Enhanced Road Safety

Road safety remains a paramount concern globally, with traffic accidents leading to significant fatalities, injuries, and economic costs. Despite ongoing efforts in infrastructure development and information dissemination, challenges persist, particularly in regions prone to diverse environmental conditions (Demir et al. 2015).

Road Accident and Fatality Statistics

Road accidents represent a critical public safety concern across the United States, leading to significant loss of life. A statistical projection estimates that 39,345 people died in motor vehicle traffic crashes in 2024 (NHTSA 2025). Within Iowa, the number of fatalities was estimated to be 358 in 2024.

Impact of Environmental Factors on Road Safety

Environmental conditions, particularly adverse weather, significantly contribute to road accidents and fatalities (Mount et al. 2019). Based on annual averages from 2019 to 2023, approximately 12% of all motor vehicle crashes in the United States are attributed to hazardous weather conditions, resulting in an estimated 268,239 injuries and 3,807 fatalities each year (FHWA 2025).

A significant portion of these incidents occur during adverse atmospheric conditions. Over 77% of weather-related crashes happen during rain or mist. Additionally, 18% of weather-related crashes occur during freezing precipitation such as snow, sleet, hail, or freezing rain/drizzle. Low visibility conditions (e.g., fog, smoke) account for 4% of weather-related crashes, and severe crosswinds account for 1% of crashes (FHWA 2025).

Rain (including mist) is a substantial factor, contributing to an estimated 10% of all vehicle crashes, 9% of all crash injuries, and 7% of all crash fatalities. This translates to 77% of weather-related crashes, 82% of weather-related injuries, and 74% of weather-related fatalities being associated with rain or mist (FHWA 2025).

Iowa’s climate presents distinct challenges that exacerbate these risks. The state experiences an average of 32 snow events annually, resulting in approximately 30 in. of snowfall, and travelers face an average of 52 days with at least minimal snowfall (Iowa DOT 2025b, Yesilkoy et al.

2024b). Beyond winter, flooding is another significant challenge for Iowa's transportation network. Research has extensively analyzed the impact of riverine floods on bridge and transportation networks in Iowa (Duran et al. 2025) and assessed flood risk for the state's railroad network (Cikmaz et al. 2023), underscoring the vulnerability of the region's infrastructure to extreme weather (Tanir et al. 2024). The combination of these varied and often extreme weather conditions creates hazards and delays for travelers, necessitating robust and real-time information systems.

Evolution of Traveler Information Systems

Effective traveler information systems are crucial for mitigating road safety risks and improving travel efficiency. These systems have evolved from basic broadcast methods to sophisticated digital platforms, yet challenges in comprehensive data delivery and user experience persist.

The Iowa DOT 511 System

The Iowa DOT manages the Iowa 511 system, which serves as a primary source of statewide up-to-date traffic information. This system provides critical data for Interstates, US routes, and state highways, including real-time updates on winter road conditions, traffic incidents, construction, truck restrictions, and road closures (Iowa DOT 2025a). It offers features such as hands-free audio announcements, zoom-enabled maps with tappable event icons, surrounding camera views, snowplow camera images and locations, real-time weather radar, and rest area information (Iowa DOT 2025a). The Iowa DOT also makes various operational data available, including real-time data from its snowplow fleet, intelligent transportation system (ITS) devices (cameras and message signs), and 511 events (Iowa DOT 2025a).

Challenges in Traditional Information Dissemination and User Experience

Traveler information systems often encounter difficulties in user experience and the effectiveness of information dissemination. Surveys indicate that a significant portion of users turn to external sources like television, radio, or third-party phone applications for weather-related travel information (60% of surveyed users) and for traffic and travel-time insights (nearly half using Google Maps or in-car navigation). The primary motivation cited for this behavior is "greater ease of use" (Sharma et al. 2015). This situation highlights a cognitive overload for drivers who must navigate multiple interfaces to gather complete information.

Furthermore, there is public frustration with the lack of immediacy in updates during severe weather events (Iowa DOT 2017). These issues collectively point to a gap in intuitive, accessible, and real-time information delivery. Users' preference for external tools like Google Maps suggests a fundamental usability and user experience gap that traditional systems struggle to bridge. The friction created by limitations in how existing information is presented and accessed often causes users to seek more intuitive and comprehensive alternatives, even if it results in fragmented information. This observation underscores that a technologically advanced, user-centric interface that leverages natural language processing, such as CARWIS, is necessary, not only to provide information from authoritative sources like the Iowa DOT but also to ensure that this information is effectively consumed and acted upon by drivers, thereby addressing the underlying usability and accessibility issues of existing systems.

AI and Conversational Agents in ITS

The advent of AI, particularly large language models (LLMs) and multi-agent systems, is revolutionizing ITS by offering unprecedented capabilities for data processing, analysis, and human-computer interaction. Previous intelligent approaches to RWIS have primarily focused on data collection, processing, and dissemination through various platforms such as websites, mobile applications, and in-vehicle systems (He et al. 2021, Souliman 2022). In addition, past proposals and solutions have explored the use of AI in data and image processing for applications such as overheight vehicle detection (Agrawal 2022), pavement monitoring (Souliman 2022), and infrastructure inspections (Catbas 2020). These studies implemented AI-based techniques to enhance the efficiency and effectiveness of data acquisition and analytics in the context of transportation systems (Nitta and Tal 2022, Gao 2022). While these efforts have contributed to improving the availability of road weather information, they often lack the capacity to provide real-time, user-friendly, and interactive communication tools that can effectively support drivers during hazardous conditions (Minge et al. 2020).

Recent developments in AI, such as the emergence of advanced conversational models like ChatGPT, have demonstrated the potential for transforming the way users access and interact with information systems (Biswas 2023, Sajja et al. 2025, Pursnani et al. 2025, Baydaroglu et al. 2022). However, the current landscape of using AI in road- and weather-related systems still lacks robust solutions that integrate state-of-the-art conversational technologies with RWIS to deliver tailored, real-time information to drivers (Zheng et al. 2023).

AI in ITS

AI technology is increasingly being applied across various facets of urban ITS, enhancing efficiency, minimizing accidents, and fostering sustainable urban growth (Zhao et al. 2025). Key applications include the following:

- **Traffic Data Collection and Processing**: AI provides accurate data support for traffic decision-making, monitoring congestion, traffic flow, and vehicle speed in real-time using sensors and cameras. Advanced sensors like global navigation satellite systems (GNSS) receivers, inertial measurement units (IMUs), cameras, radar, and lidar contribute to richer datasets, with AI algorithms handling data imperfections through techniques like data imputation and outlier detection (Zemmouchi-Ghomari et al. 2024).
- **Intelligent Driving and Traffic Safety**: AI is being applied to develop intelligent driving systems and for traffic risk prevention. It can provide insights on forthcoming traffic conditions, aiding traffic managers in the efficient planning and allocation of resources (Zhao et al. 2025).
- **Predictive Analytics**: AI enables predictive analytics to anticipate and prevent traffic issues (SmythOS n.d.).

The role of AI in ITS extends beyond mere data collection to active data enhancement and sophisticated decision support. AI algorithms do not just gather data; they actively improve the quality and utility of that data by handling imperfections, and then use it for proactive decision-making and forecasting. This elevates ITS capabilities from reactive reporting to intelligent, anticipatory management. Despite these advancements, challenges remain, including ensuring data quality, meeting real-time processing requirements, addressing computational costs, and navigating security, public acceptance, and privacy concerns (Zemmouchi-Ghomari et al. 2024).

The Transformative Role of LLMs in Information Delivery

LLMs represent a significant leap in AI capabilities, profoundly impacting how information is processed and delivered within ITS. LLMs, including multimodal large models (MLMs), offer robust support for more intelligent, safer, and efficient autonomous driving systems (Karim et al. 2025). Their core strengths include the following:

- **Natural Language Understanding and Generation**: LLMs interpret and create natural language text, enabling conversational interaction with users. This allows for intuitive communication and easy review of agent work.
- **Multimodal Input/Output**: LLMs are capable of handling multi-modal inputs and outputs such as text, voice, images, and video (Karim et al. 2025).
- **Logical Reasoning and Decision-Making**: LLMs can act as traffic controllers, leveraging their logical reasoning, scene understanding, and decision-making capabilities to optimize traffic flow and provide real-time feedback based on conditions. They can offer precise recommendations to drivers, such as yielding, slowing, or stopping (Karim et al. 2025).
- **Data Integration and Context-Awareness**: LLMs can centralize traditionally disconnected traffic control processes and integrate data from diverse sources to provide context-aware decisions (Karim et al. 2025).
- **Enhancing Data Quality**: LLM frameworks can analyze traffic crash narratives to uncover underreported crash factors, improving the quality and comprehensiveness of traffic crash records (Arteaga et al. 2025).

Furthermore, research has explored the development of novel data expert systems that integrate conversational AI agents for enhanced analytics in complex domains (Vald et al. 2024). The capabilities of LLMs can transform the delivery of travel and transportation information. By understanding natural language, processing various types of media, integrating diverse data, and applying logical reasoning, LLMs can provide highly intuitive, personalized, and actionable insights for travelers. This enables them to offer real-time recommendations and facilitate more informed decision-making for safer and more efficient journeys.

Recognizing this potential, and in response to the critical need for enhanced road safety—exacerbated by current traveler information limitations and persistent user experience gaps—CARWIS emerges as an innovative solution within the realm of ITS. This background analysis highlights a clear knowledge gap in existing research and practice, particularly regarding the accessibility and interactivity of RWIS. CARWIS seeks to bridge this gap by leveraging the transformative capabilities of AI, especially LLMs, to deliver a user-friendly, voice-enabled conversational assistant capable of providing real-time, contextually relevant information on road and weather conditions. By integrating advanced technologies, CARWIS not only builds upon prior developments in RWIS and AI but also addresses the shortcomings of current systems in terms of accessibility, interactivity, and overall user experience. Ultimately, this approach aims to advance the field of RWIS, enhance driver safety and performance during challenging conditions, and optimize the travel experience for all road users.

PROJECT OBJECTIVES

In this project, the researchers developed an AI-powered knowledge framework with voice-enabled conversational capabilities (i.e., CARWIS) that will be accessible to the public 24/7 and will generate prompt responses to natural language questions on current road and weather conditions in Iowa. The primary goal was to improve driver experience and safety by providing immediate and convenient access to dense networks of data streams and facilitating the communication of advanced analytics and forecasts to enable drivers to extract relevant knowledge from complex and distributed data resources on-demand (Sermet and Demir 2018, Sajja et al. 2023).

The objectives of this project were as follows:

1. Mitigate weather- and road condition-related accidents with real-time and accessible information
2. Infer the desired knowledge from brief natural language questions from drivers with diverse backgrounds and expressions
3. Make the system available to the public via everyday devices to eliminate technical barriers to information access and promote equity
4. Reduce the frequency of calls and smartphone usage by drivers looking for weather and road condition-related information

The following is a summary of the core responsibilities and the development process:

1. Create an extensive database of atmospheric measurement, camera, and traffic data from RWIS and other data sources
2. Design and implement a comprehensive software-as-a-service (SaaS) platform with an Agile approach in collaboration with the Iowa DOT and Aurora
   a. Create a knowledge base to semantically identify weather- and road-related phenomena in relation to RWIS and to enable inference
   b. Develop an inference engine based on a deep-learning (DL) powered auto-regressive language model (e.g., GPT-4) to extract desired knowledge and construct meaningful responses
   c. Via the CARWIS platform, provide web services that allow integration into various communication channels (e.g., Google Assistant) to enable its voice-based usage in vehicles via Android Auto and Apple CarPlay
3. Conduct a pilot study to qualitatively assess its performance and perceived benefit as part of a workshop that will include the demonstration of the platform prototype

CARWIS SYSTEM DESIGN

The CARWIS Drive Assist platform is built on the extensive expertise and know-how of the project team in hydrological web-based cyberinfrastructure development (Demir and Krajewski 2013), ontology development (Sermet and Demir 2019), knowledge systems (Sermet and Demir 2018), conversational interfaces (Sermet and Demir 2021), intelligent assistants for higher education (Sajja et al. 2022), web-based analytics (Ramirez et al. 2022), disaster analytics (Yildirim and Demir 2021), and transportation system assessment (Alabbad et al. 2022).

The CARWIS Drive Assist platform is built around four specialized AI experts, each tailored to support different driving scenarios based on user needs. These experts serve as the primary user-facing agents and operate through a dynamic function-calling framework, which enables each expert to invoke only the backend services relevant to its purpose. This modular design ensures that responses are accurate, context-aware, and aligned with the specific use case. A clear understanding of each expert's role is essential for interpreting the system's architecture and functional organization.

Expert Overview

Drive Assistant

The Drive Assistant is a general-purpose expert intended for everyday travel during non-winter conditions. It focuses on delivering data-driven insights related to weather, surface conditions, road closures, and driving safety. This expert does not rely on visual data sources such as traffic cameras or snowplow tracking.

Key Capabilities

- **Analyze Driving Conditions for a Full Route**: Get real-time information on road and surface conditions, closures, weather, and hazards along your specified route.
- **Assess Conditions at a Specific Location**: Receive localized updates for any city or highway.
- **Provide Safety-Oriented Driving Advice**: Get actionable tips and recommendations based on current driving conditions to help you plan safely.

Data Sources:

- National Weather Service
- RWIS Surface Data
- Iowa DOT 511 Winter Road Conditions
- Iowa DOT Traveler Events

Winter Expert

The Winter Expert specializes in assisting drivers during hazardous winter conditions. It synthesizes data from RWIS pavement sensors, surface temperature readings, ice percentage values, snowplow tracking data, and live camera images to provide a comprehensive view of winter-specific risks. This expert is optimized for use during snowfall, freezing temperatures, or icy road events, helping users evaluate and prepare for travel under severe conditions.

Key Capabilities

- **Analyze Winter Road Conditions for a Full Route**: Get real-time insights into winter hazards, road temperatures, and surface conditions for any route you specify.
- **Assess Winter Conditions at a Specific Location**: Get real-time information about winter weather and road conditions at any location, whether it's a city or a highway.
- **Monitor Weather Forecasts and Traffic Updates**: Receive up-to-date information on evolving weather systems, road closures, detours, and hazardous conditions either for the entire route or specific areas.
- **Check Road and Surface Status Details**: Obtain data on factors like surface temperature, moisture levels, and percentage of ice coverage, crucial for winter driving safety.
- **Track Active Snowplow Operations**: View the real-time positions of snowplows along your route or in your area to help anticipate cleared or hazardous sections.
- **View Live Road Camera Images**: Access the latest camera feeds for your chosen route or location, providing visual confirmation of conditions such as snow accumulation, ice patches, and visibility levels.
- **Highlight Winter-Specific Hazards**: Focus specifically on dangers like black ice, drifting snow, freezing rain, and limited visibility due to blizzards or fog.
- **Receive Winter Driving Safety Advice**: Get actionable tips and recommendations for safer travel based on current and forecasted conditions.

Data Sources:

- National Weather Service
- RWIS Surface Data
- Iowa DOT 511 Winter Road Conditions
- Iowa DOT Traveler Events
- Iowa DOT Snow Plow Locations
- Iowa DOT Traffic Cameras

Live View Expert

The Live View Expert is focused on the real-time visual verification of traffic and road conditions. It retrieves and analyzes camera images from Iowa DOT traffic and RWIS cameras to assess congestion, accidents, surface status, and visibility conditions, as shown in Figure 1.

This expert is primarily used when a visual assessment is needed to support travel decisions, especially in urban or high-traffic areas.

Figure 1. Live image gallery in response to a user query

Key Capabilities

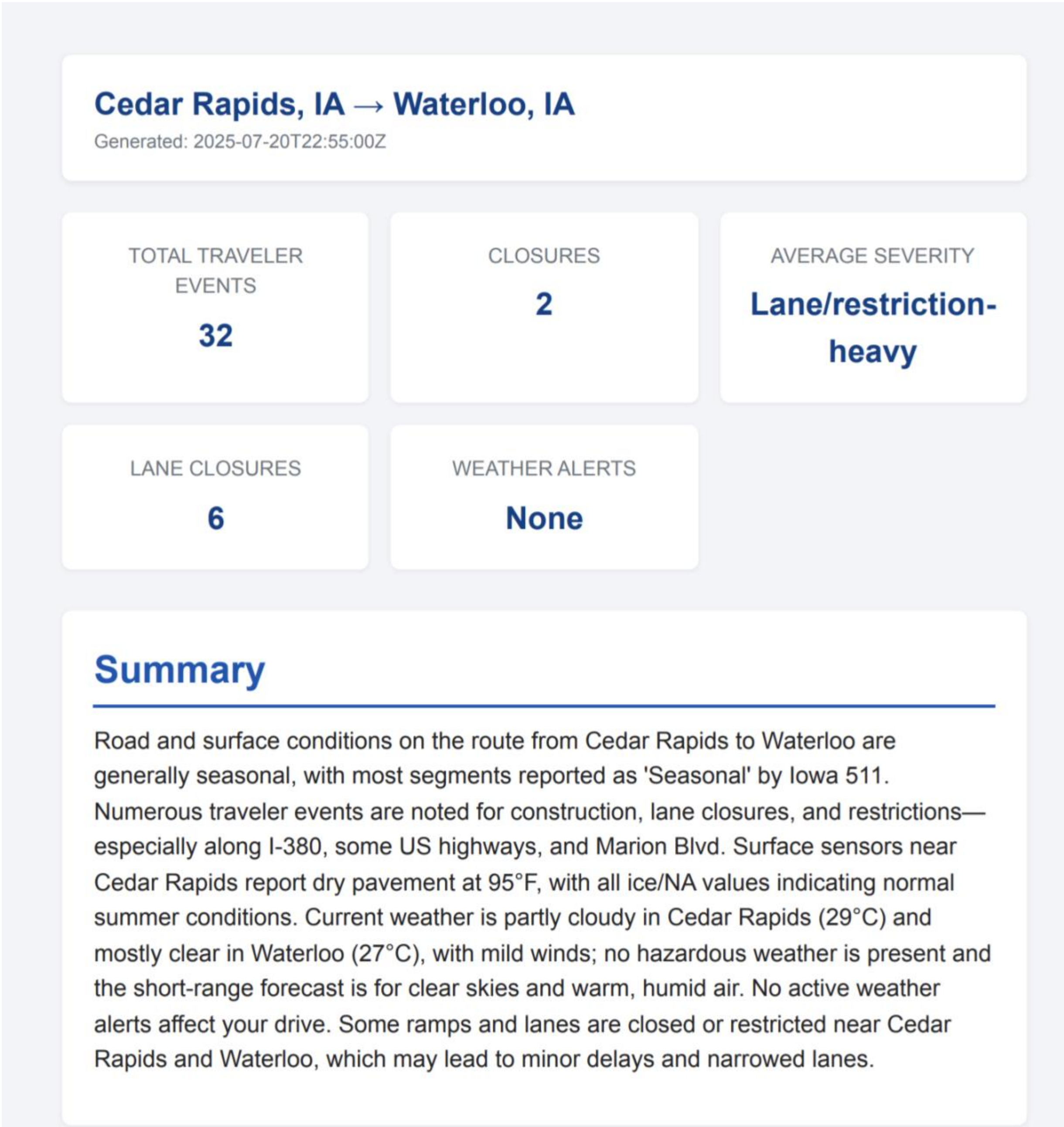
- **Analyze Driving Conditions for a Full Route**: Get visual and data-driven insights into traffic flow, road surfaces, and possible disruptions along your specified route.
- **Assess Road Conditions at a Specific Location**: View live road and traffic conditions at a city, intersection, or a highway segment of your choosing.
- **Visually Analyze Live Road and Traffic Conditions**: Use real-time camera feeds to assess traffic flow, identify congestion levels (none, mild, moderate, major), detect incidents like accidents or backups, and observe weather-related road impacts such as rain, snow, or fog.

Data Sources:

- Iowa DOT Traffic Cameras
- Iowa DOT Traveler Events
- Iowa DOT 511 Winter Road Conditions
- RWIS Surface Data
- National Weather Service

511 Data Expert

The 511 Data Expert generates structured PDF reports summarizing road and weather conditions along a specified route or location, as shown in Figures 2 and 3. It aggregates data from all sources—including weather, surface sensors, snowplow locations, and closures—into a printable format. This expert is best suited for pre-trip documentation, stakeholder reporting, and scenarios requiring an official travel summary.



Cedar Rapids, IA → Waterloo, IA

Generated: 2025-07-20T22:55:00Z

TOTAL TRAVELER EVENTS	CLOSURES	AVERAGE SEVERITY
32	**2**	**Lane/restriction-heavy**

LANE CLOSURES	WEATHER ALERTS
6	**None**

Summary

Road and surface conditions on the route from Cedar Rapids to Waterloo are generally seasonal, with most segments reported as 'Seasonal' by Iowa 511. Numerous traveler events are noted for construction, lane closures, and restrictions—especially along I-380, some US highways, and Marion Blvd. Surface sensors near Cedar Rapids report dry pavement at 95°F, with all ice/NA values indicating normal summer conditions. Current weather is partly cloudy in Cedar Rapids (29°C) and mostly clear in Waterloo (27°C), with mild winds; no hazardous weather is present and the short-range forecast is for clear skies and warm, humid air. No active weather alerts affect your drive. Some ramps and lanes are closed or restricted near Cedar Rapids and Waterloo, which may lead to minor delays and narrowed lanes.

Figure 2. Part of a PDF report generated for a user-specified route

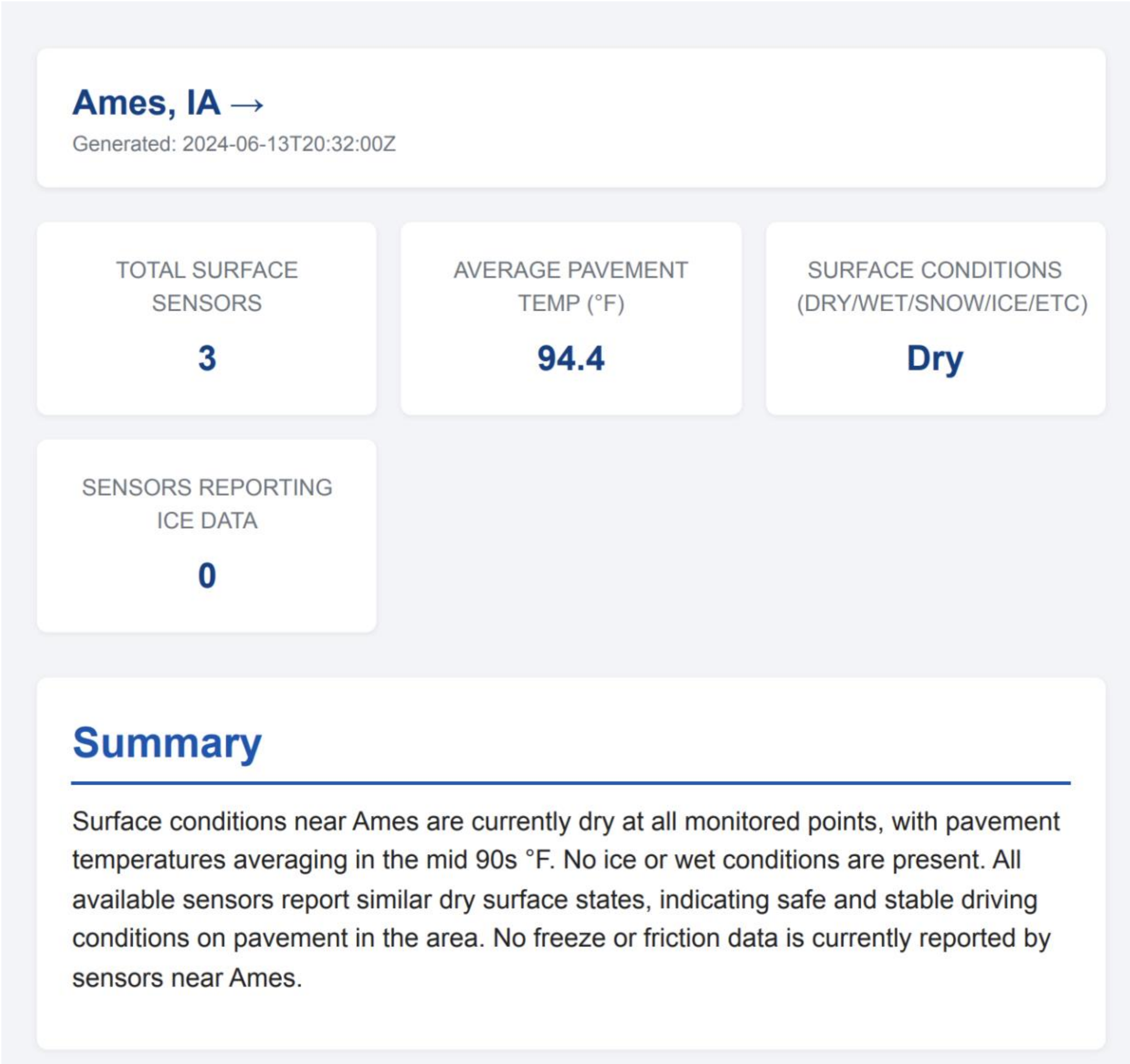


Figure 3. Part of a PDF report generated for a single location

Key Capabilities

- **Generate PDF Reports for a Full Route**: Create detailed reports summarizing driving conditions along any specified route, including road closures, surface and road conditions, weather impacts, and snowplow activity.
- **Generate Statewide Overview Reports**: Request reports covering the entire state to understand overall road status and weather-related impacts.

Data Sources:

- National Weather Service

- RWIS Surface Data
- Iowa DOT 511 Winter Road Conditions
- Iowa DOT Traveler Events
- Iowa DOT Snow Plow Locations

Not all data sources are used in every interaction; the expert determines which services to invoke based on the user's query.

Frontend User Interface

The frontend of the CARWIS Drive Assist platform is designed to provide a clean, intuitive interface for interacting with the system's AI experts. Built using React and Material UI, it enables users to select experts and submit queries in natural language. This section outlines the major user interface (UI) components and how they facilitate access to driving conditions data.

The CARWIS homepage provides users with an overview of the platform and allows them to choose from four specialized AI experts, as shown in Figure 4. The interface emphasizes clarity and simplicity, enabling users to begin their interaction without any prior training. Each expert's title includes a short description of its role to assist in selection.

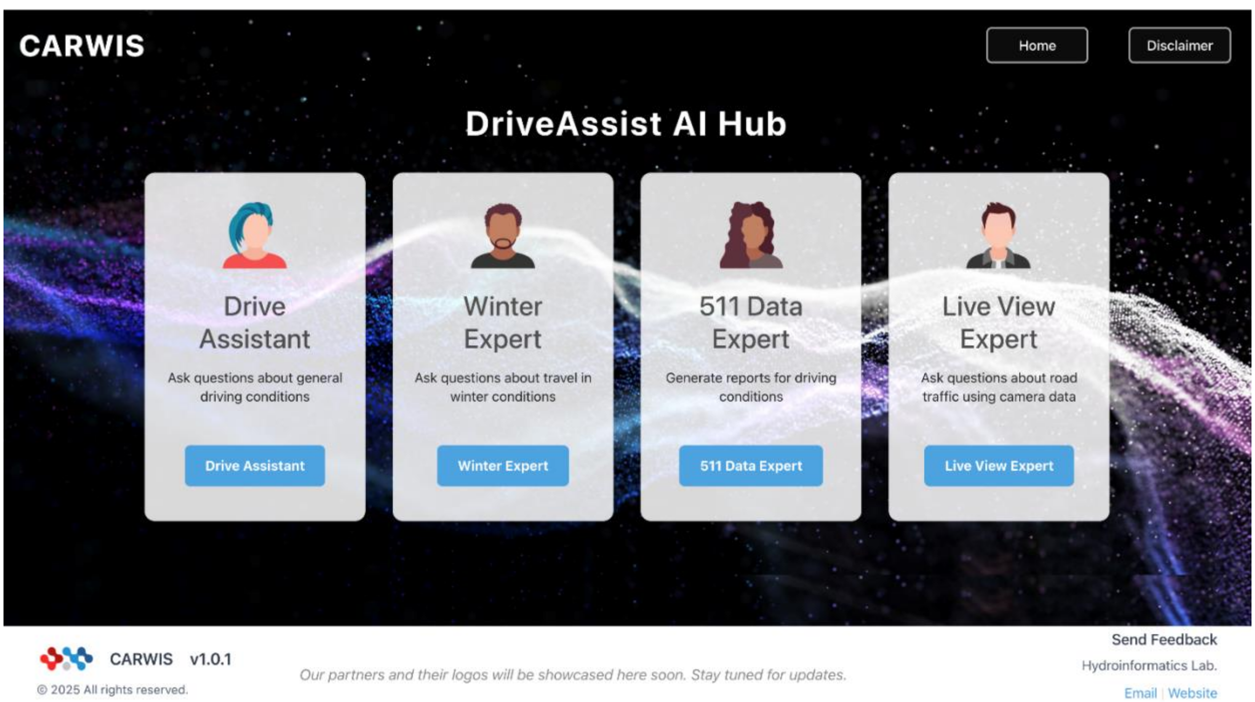


Figure 4. CARWIS homepage and AI expert selection interface

The chat interface is the primary interaction space where users can submit natural language queries to the selected expert, as shown in Figure 5. The interface supports real-time conversation, displaying system responses and camera images based on the user's request. It also includes options to download structured PDF reports when supported by the expert. The home button in the top right enables users to return to the homepage at any time, while the disclaimer button provides transparency about limitations and system usage guidelines. There is also a "Disclaimer" and "Source" shown besides each AI response. The disclaimer is a short statement that alerts users that the response may contain inaccuracies or omissions and advises consulting official sources before making travel decisions. The source identifies the authoritative data sources used to generate the response—such as the National Weather Service, Iowa DOT, or RWIS—helping users understand and trust the provenance of the information provided.

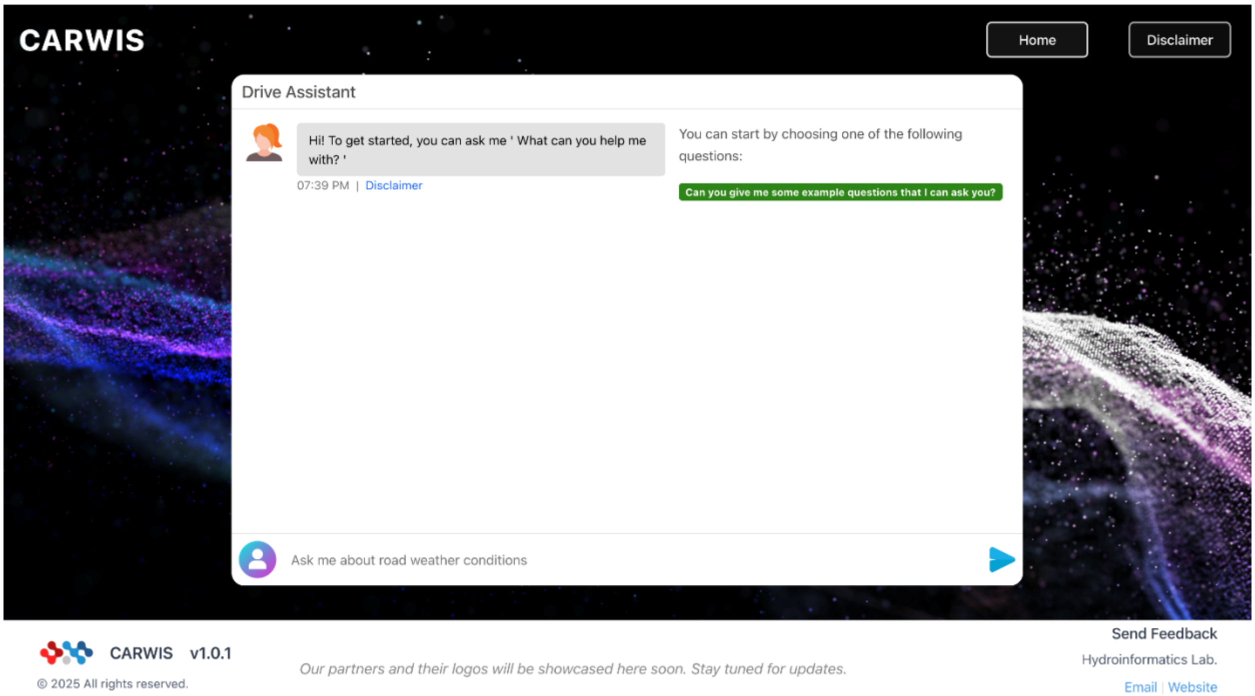


Figure 5. CARWIS chat interface for Drive Assistant

Backend Architecture

The CARWIS backend is implemented using a modular Node.js and Express framework that supports scalable integration with external data sources. It consists of several key components designed to process user requests, retrieve live data, and deliver structured responses to the frontend interface.

- **Express.js**: A minimalist web framework that provides the backbone for handling API endpoints and routing logic.
- **CORS Middleware**: Enables secure cross-origin communication between the frontend interface and backend services.
- **Axios**: A promise-based HTTP client used to efficiently manage external API requests to sources such as the Iowa DOT, RWIS, and the National Weather Service.
- **Puppeteer**: A headless Chromium browser used to generate downloadable PDF reports by rendering HTML content server-side.

- **Express Handlebars**: A templating engine used to format and populate dynamic content within report templates.
- **Dynamic Function-Calling Framework**: Powers the ability of each AI expert to selectively call relevant backend functions based on the user's natural language query, ensuring that responses are context-aware.

Web Server Configuration

To support reliable deployment and high performance under varying load conditions, CARWIS employs Nginx as a reverse proxy server to carry out the following:

- Route incoming client requests to appropriate backend services
- Enable load balancing across service instances when scaled
- Improve latency and ensures application availability during peak usage

Each expert is supported by a set of modular backend functions that retrieve and process real-time data from official sources. The following section outlines the purpose, logic, and output structure of each function that powers CARWIS.

System Data Modules

Table 1 provides a high-level summary of each function implemented in the backend.

Table 1. Summary of core backend functions in CARWIS

Function Name	Purpose	Primary Data Source
get_route_waypoints	Extracts geographic waypoints from a user-defined route	Google Maps Compute Routes API
get_iowa511_road_conditions	Retrieves road condition and pavement status data	Iowa DOT 511 Road Conditions API
get_rwis_surface_data	Retrieves surface sensor data such as pavement temperature and ice %	RWIS Surface Data API
get_weather_forecast	Retrieves current weather, forecasts, and alerts	National Weather Service API
get_snow_plow_locations	Tracks real-time snowplow locations and blade statuses	Iowa DOT Snow Plow Truck Location API
get_traveler_events	Identifies road closures, incidents, and construction events	Iowa DOT 511 Traveler Information Events API
get_camera_data	Retrieves and verifies live traffic camera images	Iowa DOT Traffic Cameras (Video Request Form API)
generate_report	Compiles all condition data into a structured PDF report	Aggregated data + Puppeteer (PDF) + Handlebars (templating)

The functions are summarized in the following sections.

get_route_waypoints

User Action

The user asks about route-based conditions (e.g., "What are the road conditions from Iowa City to Omaha?").

System Behavior

The system calls the Google Maps Compute Routes API v2 to calculate a driving route and extract intermediate geographic waypoints. These coordinates are used as reference points for spatial queries in downstream data retrieval (e.g., road conditions, weather, and surface data).

API Endpoint

https://routes.googleapis.com/directions/v2:computeRoutes

Request Parameters

- **Origin**: Latitude and longitude of the starting point
- **Destination**: Latitude and longitude of the destination
- **Travel Mode**: DRIVE
- **Routing Preference**: TRAFFIC_UNAWARE
- **Alternative Routes**: false (only primary route is computed)
- **Route Modifiers**:
  - **Avoid tolls**: false
  - **Avoid highways**: false
  - **Avoid ferries**: false
- **Language Code**: en-US
- **Units**: IMPERIAL

Response Handling

- The returned polyline is decoded using the @mapbox/polyline library.
- The polyline coordinates are converted into { latitude, longitude } format.
- An intelligent sampling algorithm selects an appropriate number of waypoints along the route
- If the route is short or includes four or fewer significant points, the algorithm returns all available waypoints; for longer routes, it increases the number of waypoints as needed to capture both key segments and community locations.
- The origin and destination points are always included.

Output

Returns a list of four { latitude, longitude } waypoint objects used for subsequent data retrieval (e.g., surface conditions, weather, cameras).

get_iowa511_road_conditions

User Action

The user asks about road conditions, pavement status, or travel restrictions for a specific location or route.

System Behavior

The system queries the Iowa DOT 511 Winter Road Conditions API using spatial filters to retrieve road condition data for the specified location or along the computed route.

API Endpoint

https://services.arcgis.com/8lRhdTsQyJpO52F1/arcgis/rest/services/511_IA_Road_Conditions_View/FeatureServer/0/query

Request Parameters

- **where**: "1=1" (return all records)
- **outFields**: * (all attributes)
- **outSR**: 4326 (WGS84 coordinate system)
- **geometryType**: esriGeometryPolygon
- **spatialRel**: esriSpatialRelIntersects
- **geometry**:
  - A square polygon buffer (0.15°) is created around each waypoint or coordinate.
  - For statewide queries, the spatial filter is omitted.

Response Handling

- Geometry objects are removed from the response.
- Returns only the attribute data relevant to road conditions.

Output

An array of road condition objects including pavement.

get_rwis_surface_data

User Action

The user asks about pavement temperature, surface moisture, ice percentage, or friction levels.

System Behavior

The system queries the RWIS Surface Data API using the same spatial filtering strategy as the road conditions function.

API Endpoint

https://services.arcgis.com/8lRhdTsQyJpO52F1/arcgis/rest/services/RWIS_Surface_Data_View/FeatureServer/0/query

Request Parameters

- **where**: "1=1" (return all records)
- **outFields**: * (all attributes)
- **outSR**: 4326 (WGS84 coordinate system)
- **geometryType**: esriGeometryPolygon
- **spatialRel**: esriSpatialRelIntersects
- **geometry**:
  - A square polygon buffer (0.15°) is created around each waypoint or coordinate.
  - For statewide queries, the spatial filter is omitted.

Response Handling

- Geometry objects are removed from the response.
- Returns only the attribute data relevant to surface conditions.
- Any value returned as 9999 is interpreted as missing.

Output

An array of surface condition objects with detailed sensor readings for pavement temperature, ice, friction, and moisture.

get_weather_forecast

User Action

The user asks about current weather, forecasts, or weather alerts.

System Behavior

The system performs a multi-step data retrieval process using the National Weather Service APIs to return localized weather information. It selects the appropriate forecast based on the user's intent (current, hourly, or daily).

API Endpoint

- **Points API**: https://api.weather.gov/points/{latitude},{longitude} used to get forecast grid endpoints and observation station list
- **Observation Station**: The system uses the 'observationStations' URL to identify the nearest weather station.
- **Current Conditions**: Retrieved from https://api.weather.gov/stations/{station}/observations/latest
- **Hourly Forecast (24 to 48 hours)**: Uses the 'forecastHourly' URL from the Points API
- **Daily Forecast**: Uses the 'forecast' URL from the Points API
- **Weather Alerts**: Retrieved from https://api.weather.gov/alerts/active?point={latitude},{longitude}

Response Handling

- Combines outputs from all sources (conditions, forecasts, alerts) into a structured response.

Output

A weather object containing the current, hourly, or daily forecast based on user intent and active weather alerts (e.g., flood, snow, storm warnings).

get_snow_plow_locations

User Action

The user asks about active snowplow trucks and their current locations or blade usage status.

System Behavior

The system calls the Iowa DOT Snow Plow Truck Location API and filters for trucks traveling faster than 3 mph to avoid idle or parked plows.

API Endpoint

https://services.arcgis.com/8lRhdTsQyJpO52F1/arcgis/rest/services/AVL_Direct_View/FeatureServer/0/query

Request Parameters

- **where**: "1=1" (return all records)
- **outFields**: * (all attributes)
- **outSR**: 4326 (WGS84 coordinate system)
- **geometryType**: esriGeometryPolygon
- **spatialRel**: esriSpatialRelIntersects
- **geometry**:
    - A square polygon buffer (0.15°) created around each waypoint or coordinate

Response Handling

- Geometry objects are removed from the response.
- Returns only the attribute data relevant to snowplow trucks.
- Differentiates between active trucks removing and not removing snow.

Output

An array of active snowplow truck objects with location and plow blade status indicators.

get_camera_data

User Action

The user asks to view live traffic conditions, verify visual road status, or access camera images.

System Behavior

The system queries the Iowa DOT Traffic Cameras Video Request Form API and applies both spatial and route-based filtering. It uses a two-pass algorithm to identify the most relevant cameras.

API Endpoint

https://services.arcgis.com/8lRhdTsQyJpO52F1/arcgis/rest/services/Traffic_Cameras_Video_Request_Form/FeatureServer/0/query

Filtering Strategy

- **Route-Based Filtering**: Applies filter ROUTE = '{route}' if a route is mentioned by the user
- **Spatial Filtering**: Uses a 0.15° buffer polygon around coordinates

Response Handling

- **Pass 1**: Find the camera closest to the requested location using Haversine distance
- **Pass 2**: Retrieve all nearby cameras images within ±0.0001° of that location (i.e., images from the same camera from different angles)
- Each image URL is validated using a five-second timeout to ensure camera is active.

Output

An array of verified camera objects containing the following:

- Image URL
- Camera description

generate_report

User Action

The user requests a downloadable PDF report containing comprehensive travel and condition data for a given route or location.

System Behavior

The system aggregates results from multiple sources and generates a structured, print-ready PDF report using server-side rendering.

Report Contents:

- Route origin and destination
- Summary overview (three to six sentences)
- Key performance indicators (e.g., number of closures, incidents)

- Sectioned data
- Traveler events
- Road and surface conditions
- Active snowplow locations
- Weather forecasts and alerts
- Actionable driving recommendations

PDF Generations:

- Uses Puppeteer for headless browser rendering
- Uses Express Handlebars to populate HTML templates with data
- Output is returned as a JSON object to the frontend, where the report is made available for download.

Output

A complete, formatted PDF report summarizing real-time travel conditions for a user-specified route or location.

Example Scenarios

This section presents detailed examples of how user queries are processed by CARWIS. Each example outlines the expert selected, the system's internal flow of function calls, and the data sources involved. By breaking down each query into its execution steps, these examples demonstrate how the system coordinates modular functions and uses geographic context to deliver relevant, real-time information.

Scenario 1

Use Query: "How are the road conditions from Des Moines to Iowa City right now?"

Expert Selected: Drive Assistant

Purpose: The user wants to understand current driving conditions between two cities. The system computes the route, samples intermediate waypoints, and performs spatial queries at each point to assess road conditions, surface data, weather, and traffic events.

The function call sequence and parameters for this scenario are shown in Table 2, and sampled waypoints are shown in Table 3.

Table 2. Scenario 1 function call sequence and parameters

Step	Function	Parameters	Purpose
1	get_route_waypoints	originLatitude: 41.58681, originLongitude: -93.62495, destinationLatitude: 41.6611, destinationLongitude: -91.5301	Compute driving route and generate four waypoints
2	get_rwis_surface_data	statewide: false, latitude: 41.58681, longitude: -93.62495	Surface data near waypoint 1
3	get_rwis_surface_data	statewide: false, latitude: 41.68585, longitude: -93.27668	Surface data near waypoint 2
4	get_rwis_surface_data	statewide: false, latitude: 41.69551, longitude: -92.35769	Surface data near waypoint 3
5	get_rwis_surface_data	statewide: false, latitude: 41.6611, longitude: -91.53017	Surface data near waypoint 4
6	get_iowa511_road_conditions	statewide: false, latitude: 41.58681, longitude: -93.62495	Road condition near waypoint 1
7	get_iowa511_road_conditions	statewide: false, latitude: 41.68585, longitude: -93.27668	Road condition near waypoint 2
8	get_iowa511_road_conditions	statewide: false, latitude: 41.69551, longitude: -92.35769	Road condition near waypoint 3
9	get_iowa511_road_conditions	statewide: false, latitude: 41.6611, longitude: -91.53017	Road condition near waypoint 4
10	get_weather_forecast	latitude: 41.58681, longitude: -93.62495, timeFrame: 'current'	Weather near waypoint 1
11	get_weather_forecast	latitude: 41.68585, longitude: -93.27668, timeFrame: 'current'	Weather near waypoint 2
12	get_weather_forecast	latitude: 41.69551, longitude: -92.35769, timeFrame: 'current'	Weather near waypoint 3
13	get_weather_forecast	latitude: 41.6611, longitude: -91.53017, timeFrame: 'current'	Weather near waypoint 4
14	get_traveler_events	statewide: false, latitude: 41.58681, longitude: -93.62495	Events near waypoint 1
15	get_traveler_events	statewide: false, latitude: 41.68585, longitude: -93.27668	Events near waypoint 2
16	get_traveler_events	statewide: false, latitude: 41.69551, longitude: -92.35769	Events near waypoint 3
17	get_traveler_events	statewide: false, latitude: 41.6611, longitude: -91.53017	Events near waypoint 4

Table 3. Scenario 1 sampled waypoints

Waypoint	Latitude	Longitude
1	41.58681	-93.62495
2	41.68585	-93.27668
3	41.69551	-92.35769
4	41.66110	-91.53017

Scenario 2

Use Query: "I've heard there's construction on US-20 west of Dubuque. Can you confirm impacts and show any camera views of the area?"

Expert Selected: Live View Expert

Purpose: Identify any active construction or incidents and provide live camera views of the specified area.

The function call sequence and parameters for this scenario are shown in Table 4.

Table 4. Scenario 2 function call sequence and parameters

Step	Function	Parameters	Purpose
1	get_traveler_events	statewide: false, latitude: 42.4697, longitude: -90.6987	Events near specified location
2	get_camera_data	route: US 20, latitude: 42.4697, longitude: -90.6987	Camera images near specified location

Scenario 3

Use Query: "Are snowplows currently active on my route between Ames and Fort Dodge?"

Expert Selected: Winter Expert

Purpose: Determine whether snowplow trucks are currently active along the user's specified route.

The function call sequence and parameters for this scenario are shown in Table 5, and sampled waypoints are shown in Table 6.

Table 5. Scenario 3 function call sequence and parameters

Step	Function	Parameters	Purpose
1	get_route_waypoints	originLatitude: 42.0308, originLongitude: 93.6319 destinationLatitude: 42.4975, destinationLongitude: -94.1688	Compute driving route and generate four waypoints
2	get_snow_plow_location	latitude: 42.03094, longitude: -93.63185	Active snowplows near waypoint 1
3	get_snow_plow_location	latitude: 42.23742, longitude: -93.62164	Active snowplows near waypoint 2
4	get_snow_plow_location	latitude: 42.45015, longitude: -93.89152	Active snowplows near waypoint 3
5	get_snow_plow_location	latitude: 42.49751, longitude: -94.1688	Active snowplows near waypoint 4

Table 6. Scenario 3 sampled waypoints

Waypoint	Latitude	Longitude
1	42.03094	-93.63185
2	42.23742	-93.62164
3	42.45015	-93.89152
4	42.49751	-94.1688

Summary

These scenarios demonstrate how CARWIS processes natural language queries by mapping them to a coordinated set of modular functions. Each function retrieves data for specific locations, and their outputs are aggregated and passed to the AI expert, which synthesizes the information into a coherent, user-friendly response.

DATA SOURCES

CARWIS Drive Assist brings together data from multiple official sources to provide timely and accurate information about road and weather conditions across Iowa. All data are obtained from trusted government agencies, ensuring both reliability and consistency.

Table 7 summarizes the types of data retrieved from each Iowa DOT source and how they support the system's functionality. It is important to note that CARWIS is not intended to answer arbitrary queries about these datasets.

Table 7. Description of official data sources

API Name	Output Fields
Iowa 511 Winter Road Conditions	SEGMENT_ID ROUTE NAMEID LONG_NAME DISTRICT SUBAREA PRIMARY_MP PRIMARY_LATITTUDE PRIMARY_LONGITUDE SECONDARY_MP SECONDARY_LATITUDE SECONDARY_LONGITUDE HL_PAVEMENT_CONDITION ROAD_CONDITION CARS_MSG_UPDATE_DATE CARS_MSG_INITIAL_DATE DISTRICT_NUMBER COST_CENTER CONDITION_NOT_NORMAL_START CONDITION_NOT_NORMAL_END CONDITION_NOT_NORMAL_ELAPSED ROUTE_NAME ROUTE_SEG_INDEX REST_UPDATED PREVIOUS_ROAD_CONDITION CONDITION_CHANGE SEGMENT_LENGTH_MI ROAD_CONDITION_CODE PREVIOUS_CONDITION_HL_PHRASE PREVIOUS_CONDITION_PH_PHRASE

API Name	Output Fields
511 Traveler Information Events - Iowa	EndTime ID ExpireDate ExpireTime IssueDate IssueTime Priority Route StartTime UpdateDate UpdateTime ORGID Gisupdated STYLE Headline Phrase Cause Restrict_ Msg0 Desc0 Desc1 Linktxt EditDate
Snow Plow Truck Location AVL (Iowa DOT)	LABEL XPOSITION YPOSITION HEADING VELOCITY ROADTEMP AIRTEMP PREWETMATERIAL SOLIDRATE LIQUIDRATE PREWETRATE FRONTPLOWSTATE RIGHTWINGPLOWSTATE
Traffic Cameras Video Request Form	Desc_ ImageURL

EVALUATION

Methodology

To evaluate the usability, effectiveness, and relevance of CARWIS, the researchers conducted a post-usage survey targeting transportation professionals and domain experts. Participants were provided access to both CARWIS and the survey, allowing them to explore the system at their own pace and submit feedback based on their interactions. This feedback mechanism ensured that impressions were fresh and directly informed by recent experience.

Survey Design

The survey was structured to collect both quantitative and qualitative feedback, allowing for a comprehensive assessment of user experience and agent performance. Questions were grouped into three primary categories: General System Usability and Value, Agent-Specific Evaluation, and Cross-Agent Comparison and Forward Planning

General System Usability and Value

These Likert-scale questions assessed overall usability, clarity of information, timeliness of responses, and perceived value of the system for integration into agency workflows. Example items included the following:

- CARWIS was easy to use.
- The agents' responses were timely.
- The platform would fit well with current DOT operations.

Agent-Specific Evaluation

Each CARWIS expert—Drive Assistant, Winter Expert, Live View Expert, and 511 Data Expert—was evaluated through a tailored set of Likert-scale questions assessing ease of interaction, relevance and clarity of responses, trust in the data, and likelihood of real-world use.

Users were also asked to rate how helpful each expert was in common scenarios specific to that expert's domain (e.g., trip-specific summaries, live traffic monitoring, winter driving advice).

Additionally, open-ended text fields invited users to describe usage scenarios, report issues, and suggest improvements for each expert.

Cross-Agent Comparison and Forward Planning

The final section gathered user perspectives on the distinctiveness of each agent, potential integration with existing DOT systems, and priorities for future development.

These questions included both Likert-scale responses and open-ended text input to capture user priorities and broader feedback on CARWIS use cases.

Rationale behind Question Design

The survey included a mix of structured Likert-scale questions and open-ended prompts. This approach allowed for both measurable feedback and more detailed suggestions or reflections from participants.

Both general and agent-specific questions were asked:

- General questions captured impressions of the utility, clarity and reliability of the overall system.
- Agent-specific questions evaluated how well each expert fulfilled its intended role, including the relevance, clarity, and usefulness of the information it provided.

Survey Results

The eight valid survey responses provided both quantitative ratings and qualitative feedback on CARWIS's overall usability and on each of its four AI experts. The following sections present the findings, organized into general system metrics, expert-specific performance, and open-ended user comments.

General System Metrics

- All eight participants used the Drive Assistant.
- Six used the Live View Expert.
- Five used the Winter Expert.
- Five used the 511 Data Expert.

Overall Usability and Fit

Figure 6 displays user ratings across five general system evaluation items. Overall, participants responded favorably to the usability of the CARWIS platform. Seven out of eight users agreed or strongly agreed that the system was easy to use, while only one participant expressed strong disagreement.

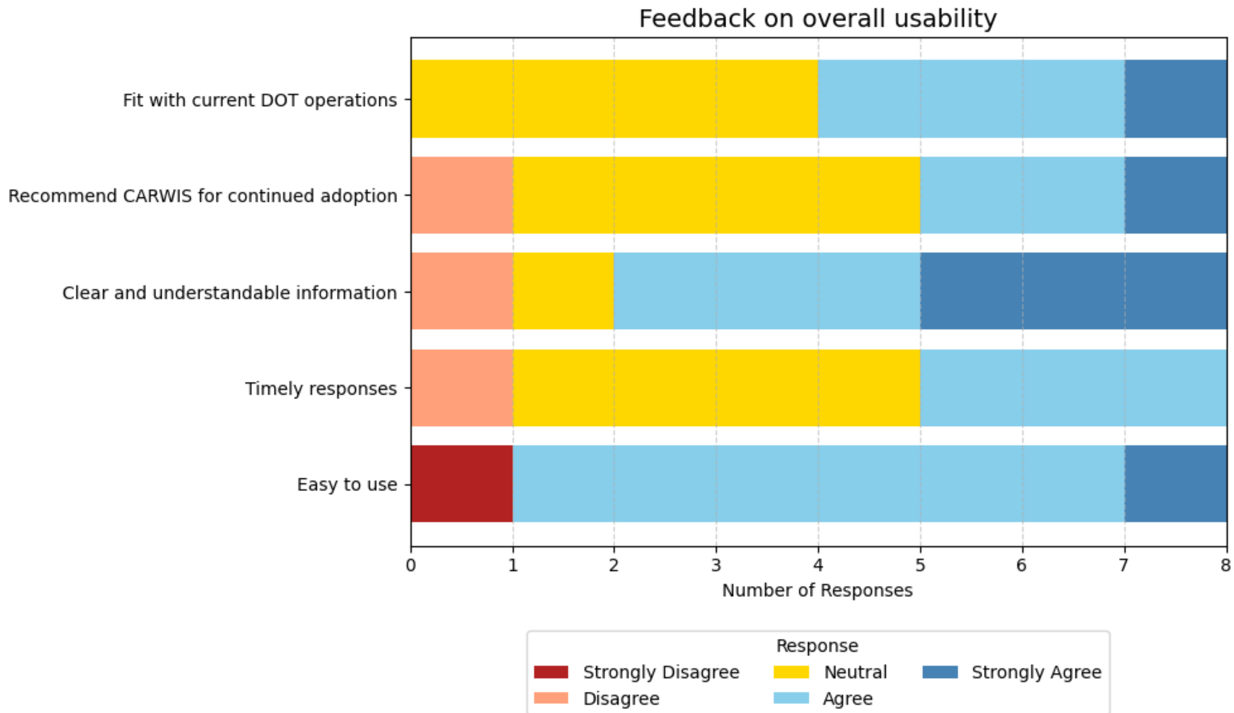


Figure 6. User feedback on overall system usability

Half of the respondents (four out of eight) agreed or strongly agreed that CARWIS provided clear and understandable information, though one participant disagreed with this statement. This suggests that while clarity was generally sufficient, it may vary depending on context or expert usage.

Perceptions of response timeliness were more mixed. Only three participants agreed or strongly agreed that the agents' responses were timely, while one participant explicitly disagreed and the majority (four respondents) remained neutral—indicating a clear opportunity for performance improvement in this area.

When asked whether they would recommend CARWIS for continued evaluation or adoption within their agency, most participants gave neutral or positive responses. Two participants agreed, one strongly agreed, four remained neutral, and one respondent disagreed.

Finally, responses to the platform's alignment with current DOT operations were moderately favorable. Five participants agreed or strongly agreed that the platform fits well with existing workflows, while the remaining three were neutral.

These results suggest that users generally found CARWIS intuitive and relevant, but improvements in response speed and clarity could increase confidence and adoption.

Figure 7 shows participant perceptions of CARWIS's overall value, agent distinctiveness, and integration potential within existing DOT systems. The majority of respondents (seven out of eight) agreed that CARWIS agents provided value beyond tools currently available at their agencies. This reflects a strong endorsement of the platform's novel capabilities.

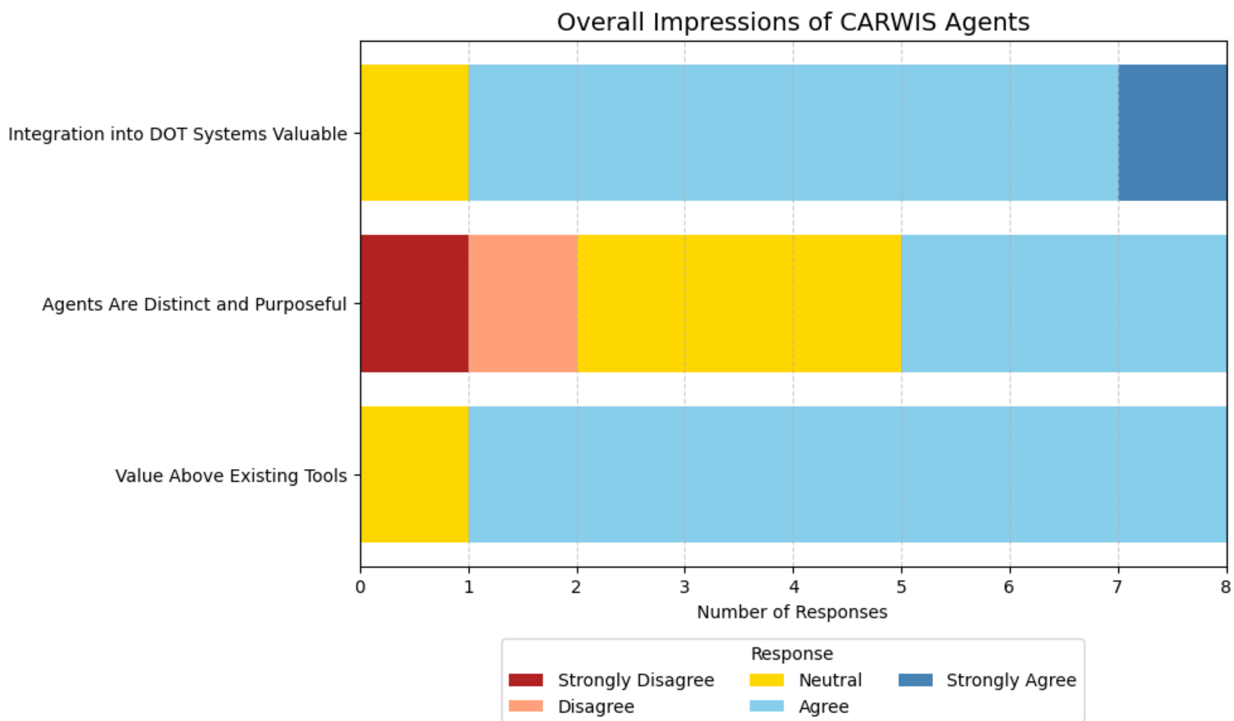


Figure 7. General user feedback on CARWIS agents

Support was similarly high for the idea of integrating CARWIS features into existing DOT systems like Iowa 511, with six respondents agreeing and one strongly agreeing. This suggests that participants saw potential for CARWIS to complement or enhance current operational workflows.

In contrast, responses were more varied regarding the distinctiveness of the individual agents. While four participants agreed that the agents serve different purposes well, three were neutral, and one respondent strongly disagreed. This indicates an area for improvement: ensuring clearer functional differentiation among the agents to minimize user confusion and maximize usability.

Together, these findings suggest that while CARWIS is broadly perceived as valuable and integrable, future iterations should focus on improving clarity between expert roles to better support user expectations and operational needs.

Expert-Specific Metrics

For each expert, the researchers aggregated the primary ease-of-use questions and the scenario-helpfulness ratings.

Drive Assistant

Overall, participants responded positively to the Drive Assistant across all evaluated dimensions. All eight respondents found the agent easy to interact with and relevant to their needs. As shown in Figure 8, seven out of eight (88%) agreed or strongly agreed that the agent provided actionable insights, and the same proportion indicated trust in the accuracy of its information. Five participants expressed confidence in using the Drive Assistant in real operational settings, while two remained neutral and one disagreed.

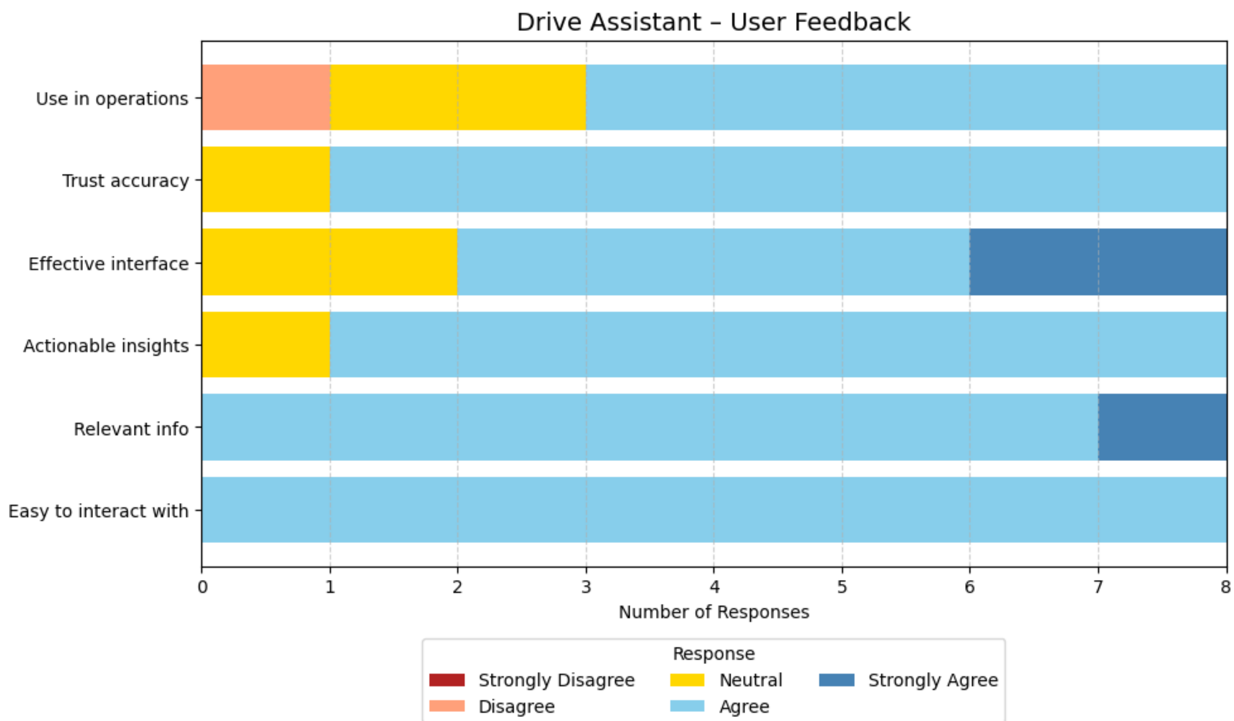


Figure 8. Summary of user feedback for Drive Assistant

Ratings for the natural language interface were slightly more mixed: while most participants found it effective, two marked it as neutral, highlighting room for improvement in tailoring the phrasing and delivery of responses.

Scenario-specific helpfulness ratings were generally strong, as indicated in the following:

- Trip-specific road and weather summaries and dynamic safety advice were each rated as "Very helpful" by five participants (63%) and "Somewhat helpful" by three (38%).

- Context-aware follow-up Q&A was rated “Very helpful” by six participants (75%) and “Somewhat helpful” by one (13%), with one participant not responding to this item.

Winter Expert

Four respondents evaluated the Winter Expert. As shown in Figure 9, all four agreed that it was easy to interact with and provided relevant, actionable insights on winter hazards. Trust in the accuracy of its data was also consistently positive. Three out of four indicated that they would use the agent operationally in winter response scenarios, while one disagreed.

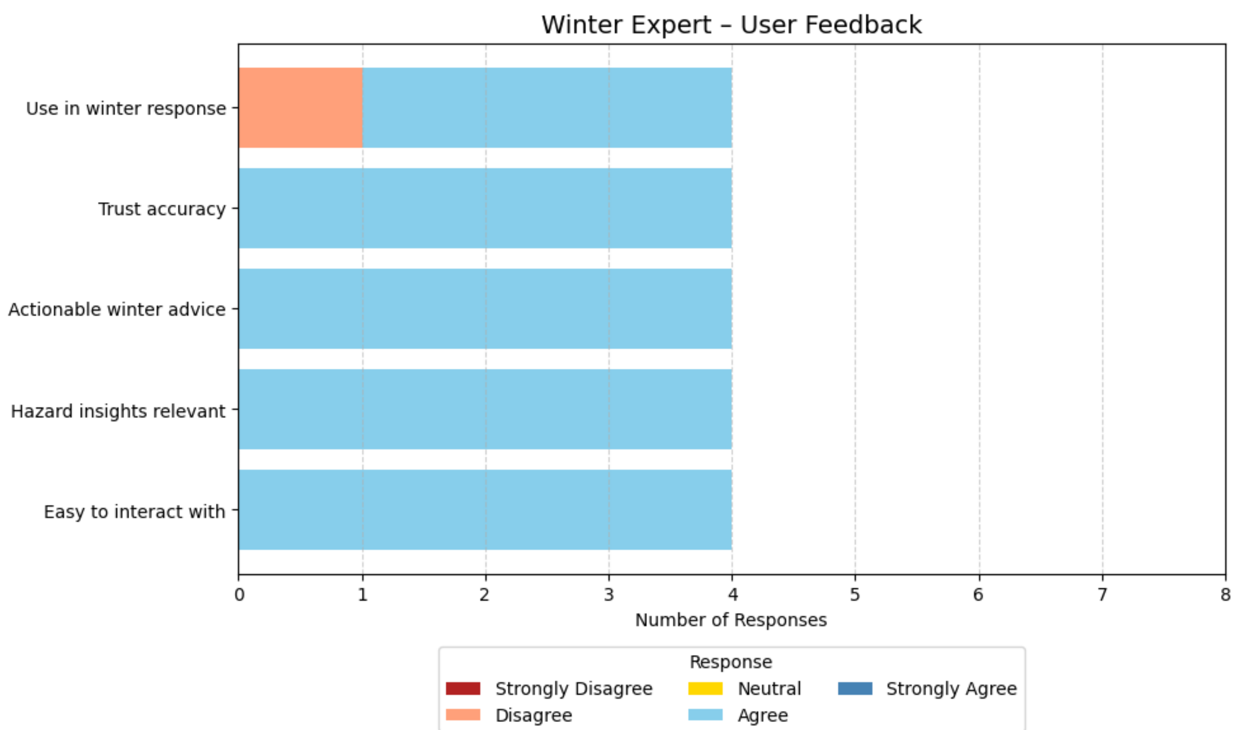


Figure 9. Summary of user feedback for Winter Expert

Scenario-specific helpfulness ratings were as follows:

- **Hazard identification and alerting for imminent winter threats**: Three respondents rated it “Very helpful” and one rated it “Somewhat helpful.”
- **Pre-trip winter driving preparation**: Two respondents rated it “Very helpful” and two rated it “Somewhat helpful.”

The results indicate that the Winter Expert performs reliably in returning relevant, actionable, and trustworthy information for winter-specific conditions. However, as one respondent explicitly noted, they tested the Winter Expert in July, when icy conditions were not present. Although the agent correctly reported “no icy roads,” the lack of actual winter conditions limited a full evaluation of its performance under real-world operational demands.

Live View Expert

Seven respondents evaluated the Live View Expert. As shown in Figure 10, the results show strong consistency, with all seven respondents selecting “Agree” or “Strongly Agree” for ease of interaction and the relevance of live road and camera data. Similarly, all respondents agreed that they received actionable insights, indicating that the assistant’s outputs were practically useful.

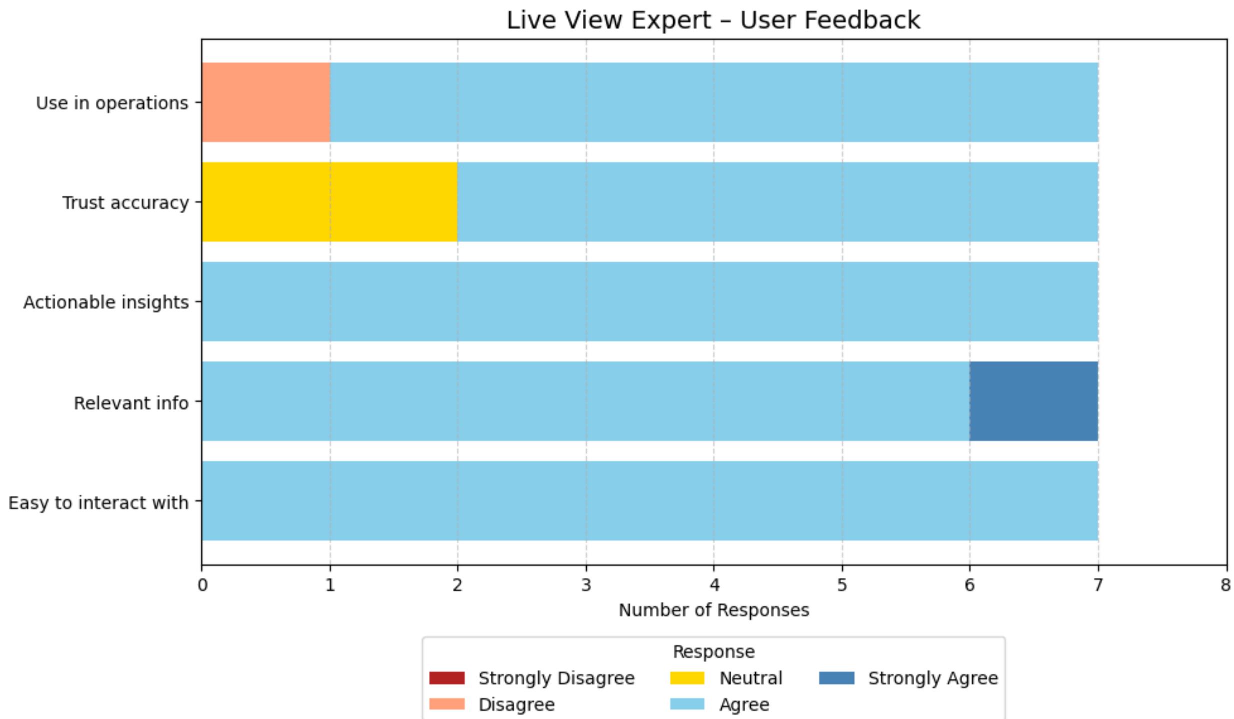


Figure 10. Summary of user feedback for Live View Expert

Two participants selected “Neutral” when asked about the trustworthiness of traffic and hazard information, suggesting some uncertainty in the system’s ability to consistently detect relevant conditions. One respondent marked “Disagree” for their likelihood of using the agent in real-time road and traffic monitoring, which may be related to these accuracy concerns.

Regarding scenario-specific helpfulness, all respondents rated viewing live traffic/camera feeds as “Very helpful.” Six participants rated using the agent for route planning as “Very helpful,” while one rated it as “Somewhat helpful.” However, automatic accident or hazard detection received more mixed ratings—three participants selected “Somewhat helpful” and three selected “Very helpful,” implying that this functionality may need refinement.

The Live View Expert was well received overall, with high marks for usability, relevance, and the quality of camera-based information. However, two participants expressed reservations about the accuracy of condition detection. One specifically noted that the system occasionally missed visible hazards like wet roads. These results suggest that while the agent’s camera integration is a valuable feature, improving interpretive consistency and hazard detection should be a focus for future development.

511 Data Expert

For the 511 Data Expert, all four respondents agreed that the agent was easy to interact with and that the incident and condition reports were relevant and actionable, as shown in Figure 11. All four respondents trusted the accuracy of the data. However, when asked whether they would likely use the agent to generate reports or integrate with DOT systems, responses were slightly more mixed—two selected “Neutral” while two others selected “Strongly Agree” and “Agree,” respectively.

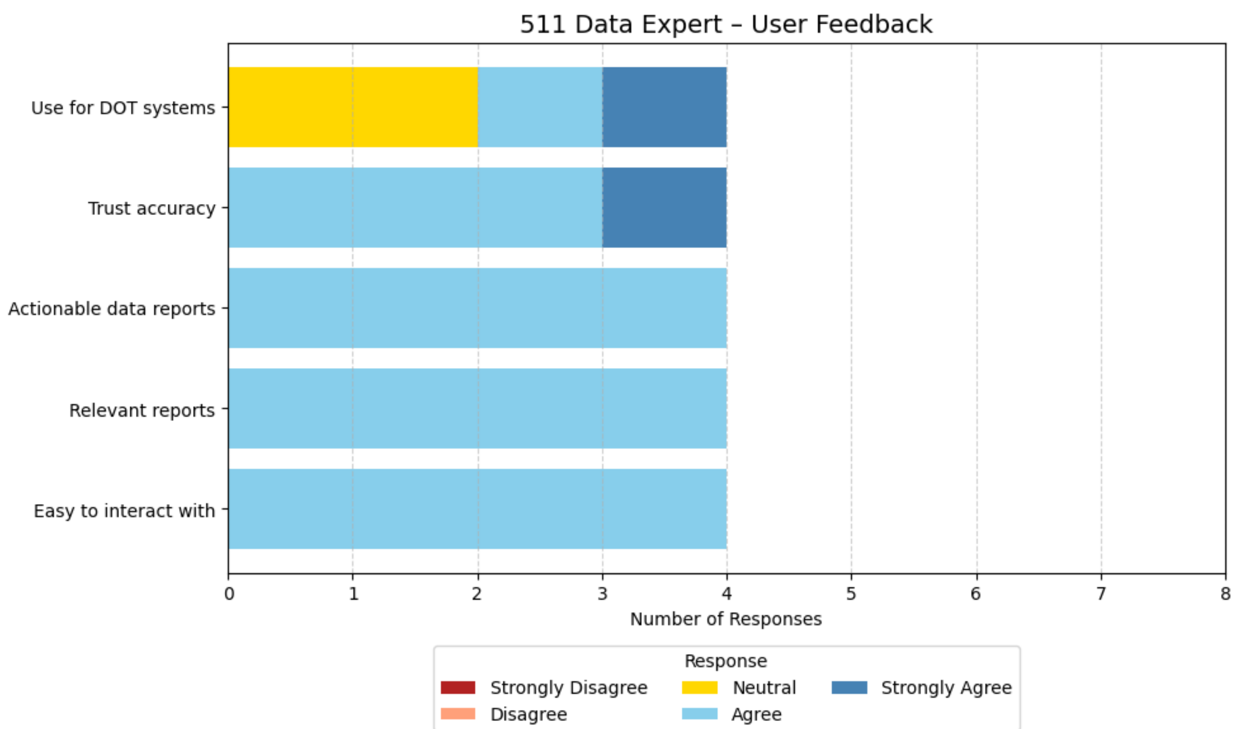


Figure 11. Summary of user feedback for 511 Data Expert

Helpfulness ratings for specific use cases also varied. All respondents rated the tool as at least “Somewhat helpful” across the three task areas. Generating route-based reports and accessing road surface analytics were especially well received, with three participants selecting “Very helpful” or “Extremely helpful.” However, responses to accessing incident/closure summaries indicated room for improvement as two users selected “Somewhat helpful.”

General Comments and Suggestions

User feedback highlighted several recurring themes related to the clarity, speed, and modality of CARWIS interactions. A common concern was response verbosity, with multiple participants noting that answers—particularly from the Drive Assistant—were too long for practical use in real-time driving scenarios. Suggestions emphasized the need for more concise, digestible outputs, especially when users are seeking quick summaries.

Response speed was another frequently mentioned issue. Several users described delays of up to a minute before receiving answers, which some found frustrating or unexpected. One respondent recommended including a loading message or estimated wait time to better manage expectations.

Participants also expressed a desire for richer visual context—such as map visualizations—to accompany traffic camera views and routing information. The absence of maps made it harder to relate textual or image-based results to geographic locations. This feedback was particularly noted in interactions with both the Drive Assistant and 511 Data Expert.

Comments on agent-specific behavior revealed mixed impressions. While some users appreciated the Live View Expert's ability to interpret camera feeds, others pointed out inconsistencies in detecting wet roads or summarizing detour routes. One participant noted that AI-like inconsistencies, such as varying answers to similar questions, reduced confidence in the system's reliability. However, internal testing suggests that such inconsistencies may be partly attributable to differences in data availability across agents. For instance, if RWIS surface sensors are temporarily inactive, the Drive Assistant may not detect wet pavement even when the Live View Expert still does through camera analysis. These underlying limitations in real-time sensor coverage could explain some of the variation in responses across agents.

A few users commented on the overall design and structure of the agent system, with one suggesting that the four experts felt redundant in purpose and could be merged into a unified assistant. Others expressed interest in a more adaptive interface, where users could pose questions and have the system internally determine which expert(s) to query, rather than manually selecting one each time.

Finally, respondents proposed enhanced interaction modes, such as voice input or Siri-like functionality, to improve accessibility and ease of use in real-world scenarios. Several emphasized the importance of timestamping data and filtering out unnecessary details to make the responses more efficient and relevant.

Summary of Evaluation Findings

The evaluation results suggest that CARWIS is broadly viewed as a promising and usable system, with participants expressing positive sentiments across most dimensions of agent functionality, usability, and integration potential. Respondents found the interface intuitive and the agent responses generally relevant, actionable, and aligned with real-world decision-making needs. The Drive Assistant and Live View Expert, in particular, received consistently strong responses for their utility in operational contexts.

At the same time, feedback also identified key areas for improvement. Several users highlighted the need for more concise responses, better formatting, and clearer timestamps. Response delays were a recurring concern, suggesting optimization opportunities on the backend. Agent distinctions, while conceptually clear, were not always apparent to users in practice, indicating potential benefits from tighter integration or an adaptive routing mechanism that selects the appropriate expert automatically.

Overall, the survey indicates a solid foundation for CARWIS, with meaningful opportunities to refine the system for greater clarity, speed, and operational fit. The insights gathered will help shape the next phase of development, ensuring that CARWIS continues evolving to meet the real-world demands of transportation professionals.

CONCLUSION

The CARWIS Drive Assist platform represents a meaningful advancement in providing users—particularly transportation professionals—with timely, context-aware insights to support safer driving, better operational decisions, and improved access to critical road and weather data. By integrating multiple real-time data sources and presenting them through natural language interfaces, the system offers users an intuitive way to access critical information—whether for trip planning, winter hazard assessment, live traffic monitoring, or detailed incident reports.

Survey results from early evaluations indicate high usability, particularly for the Drive Assistant and Live View Expert, with consistent agreement that CARWIS adds value beyond currently available tools. While feedback highlighted areas for improvement—such as making responses more concise, improving communication when data are limited, and offering more user-friendly visual outputs such as maps—it also confirmed that the system is built on a strong foundation and aligns well with user needs.

As the platform continues to evolve, prioritizing real-world performance testing (especially in winter conditions), enhancing speed and precision, and exploring unified or voice-based interfaces will be key to broader adoption. Overall, CARWIS presents a scalable framework for intelligent road information systems and holds significant potential for integration into existing DOT workflows.

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