High-Level Design

CASCADE GATEWAY ADVANCED BORDER INFORMATION SYSTEM (ABIS) DESIGN PROJECT

whatcom council of governments

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1. OVERVIEW

1.1. Background

In 2023, the Whatcom Council of Governments (WCOG) was awarded funding to complete the Cascade Gateway Advanced Border Information System (ABIS) Stage 1 Design Project. Funding was provided through the U.S. Department of Transportation's (USDOT) Strengthening Mobility and Revolutionizing Transportation (SMART) Grants Program to meet its goal of using new technologies and approaches to target real-world challenges and create benefits.

This project has evaluated technologies to replace and improve aging wait time systems at the Cascade Gateway system of border crossings between the Lower Mainland of British Columbia and Whatcom County, Washington State.

On December 16, 2024, the Washington State Department of Transportation (WSDOT), as designee of WCOG, was awarded funding for Stage 2. In 2025, WSDOT will finalize the grant agreement with the SMART Grants Program team, then meet with project partners to start the development of the detailed design and implementation plan.

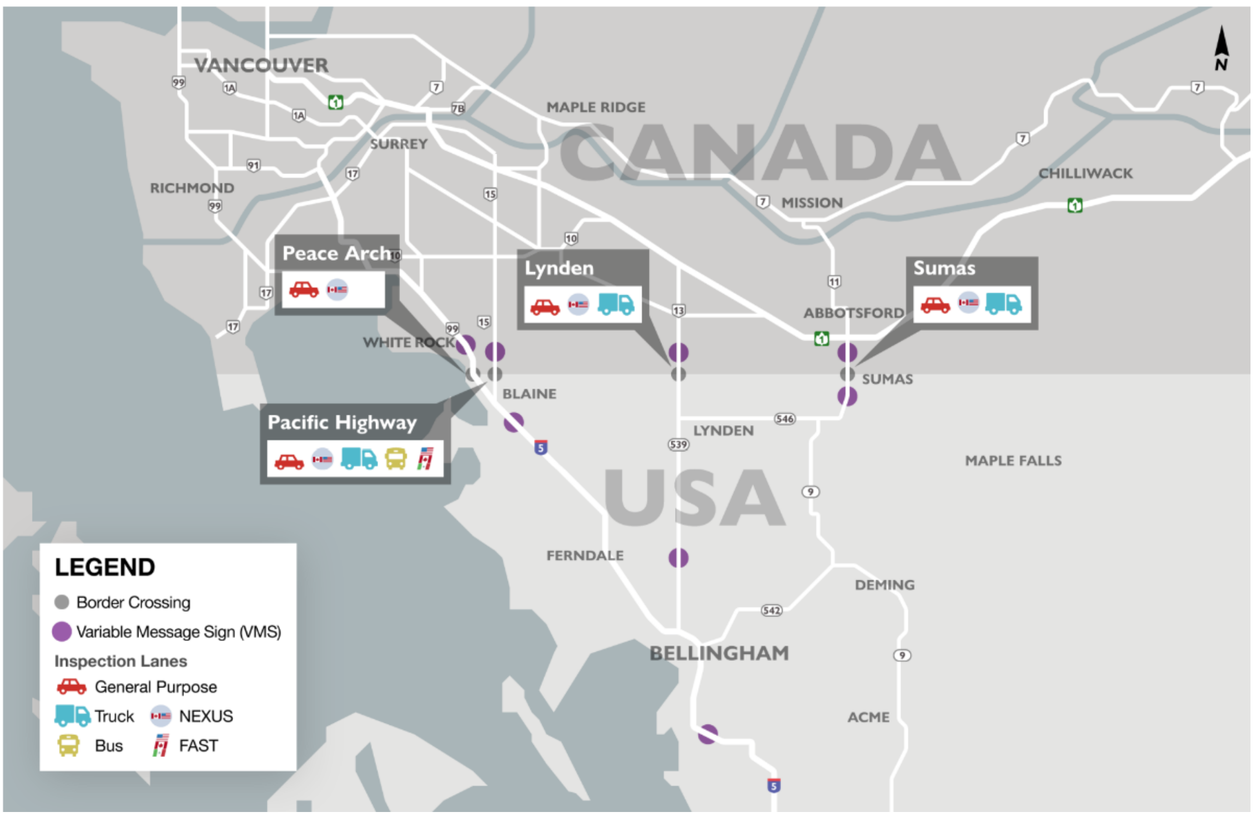


Figure 1. The Cascade Gateway ABIS Project Area Overview

1.2. Introduction

This report serves as the High-Level Design (HLD) document, which serves as a critical bridge between the conceptual understanding of the system and its detailed implementation.

A high-level design sets the foundation and overall structure of a project, while a *detailed* design dives into the specifics and technicalities needed to bring the system to life. The differences between an HLD and a Detailed Design are as follows:

- **High-Level Design**
  - Provides a big picture view of the system architecture and how major components work together (Bluetooth/Wi-Fi readers, radar detection, BWT App, interfaces to existing systems, etc.)
  - Focuses on major components, key functionalities, and stakeholder agency needs (e.g., business requirements)
  - Proposes broad technology solutions (i.e., using AI for automated data analysis and prediction)
  - Includes a diagram that lays out all the project components and deployment locations
  - Does not provide details of how each component will be built
  - Helps to get consensus from stakeholders
- **Detailed-Level Design**
  - Includes an in-depth description of each component and subsystems (i.e., detailed architecture)
  - Decomposes business/functional requirements further into operational, system, agency interface communication requirements, and more
  - Specifies the hardware and software components needed to achieve the requirements
  - Specifies in detail how the system is implemented, configured, tested, and accepted
  - Defines the specific guidelines and specifications from partnering agencies to be followed
  - Has all the information needed to implement the solution in the field.

Therefore, this HLD translates user needs and system requirements into a structured design that outlines the high-level system's architecture, major components, and component interactions. This document can serve as an architectural blueprint to define the ABIS' overall structure, including the major subsystems such as Bluetooth/Wi-Fi Readers, Radar Detection, the Border Wait Time (BWT) App's roles, and the relationships between them. This helps in visualizing how the system will function. It will also specify key components and modules needed; what technologies, tools, and platforms will be needed; and how data and communication will flow between the components of the system.

The HLD also addresses the ABIS' scalability needs to ensure the design can handle varying levels of traffic and data loads with an eye on performance. It will be the foundation for the Detailed-Level Design to be developed in the next stage of the project.

2. HIGH-LEVEL DESIGN

The cornerstone of high-level system design consists of the high-level system architecture. The following sections provide additional details about the high-level system architecture design.

2.1. High-Level System Architecture

The high-level system architecture of the ABIS serves as a blueprint that illustrates how the various hardware and software components of the system are interconnected and communicate to achieve the project's goals and objectives. The ABIS is envisioned as a seamless integration of various technologies designed to provide real-time and predictive wait times to border crossers and stakeholder agencies. This system leverages field components such as Bluetooth/Wi-Fi reader and radar vehicle detection systems to collect data on vehicle movements and wait times. Additionally, a dedicated BWT App serves as an additional data source and disseminates this information to users, enhancing their border crossing experience and aiding in efficient border management. The high-level system architecture is crucial for the following reasons.

- **Visualization of System Components**: It provides a clear and comprehensive visual representation of all the system components.
- **Communication and Coordination**: The architecture diagram shows the data flow between the field devices, the border wait time app and the agency central systems. This data includes but is not limited to number of vehicles, lanes open, average processing times, and back of the queue by lane type including truck lanes. This information facilitates effective communication and coordination among project stakeholders.
- **Integration and Interoperability**: The ABIS architecture highlights how Bluetooth/Wi-Fi readers, radar detection system, BWT App, HAR, DMS/VMS, and stakeholder agency systems and technologies are integrated to work together seamlessly. This is particularly important for ensuring that data collected from various sources is accurately processed and utilized.
- **Agency Interfaces**: It outlines interfaces between the BWT system and various border stakeholder agencies that show how data is shared among transportation and border enforcement agencies.
- **Scalability and Flexibility**: A well-defined architecture allows for scalability and flexibility, making it easier to incorporate new technologies or expand the system to additional border crossings in the future for at-scale deployment.
- **Performance and Reliability**: The architecture can highlight data exchange bottlenecks that may impact performance and reliability.

Security and Compliance: The architecture also addresses security measures and compliance with relevant regulations such as FedRamp, NIST-500, C-V2X guidelines and other applicable ITS standards for center-to-center communication, ensuring that data is protected and the system adheres to all the legal and security requirements. In Figure 2, the BWT app architecture leverages Google Cloud Platform to provide users with real-time, accurate predictions of border wait times. It gathers data from multiple external sources, including Bluetooth/Wi-Fi, radar, historical data, and third-party APIs, which is then streamed to a centralized border data warehouse. This setup enables the system to analyze incoming information instantaneously, ensuring that users have access to the latest data through the app. The architecture is designed to prioritize speed and precision, ensuring a seamless experience for users who depend on timely updates for travel planning.

The technical backbone of this architecture involves components like Google Cloud Pub/Sub for message handling, Dataflow for stream processing, and BigQuery for structured data storage and analytics, Google maps for intuitive interface and Google Looker for Dashboards. Together, these tools create a highly efficient pipeline that processes and refines raw data into actionable insights. The architecture also supports advanced analytics and machine learning models, which are continuously updated with the latest data to improve prediction accuracy. Its design accommodates high data volumes and dynamic conditions, ensuring scalability and reliability for real-time operations.

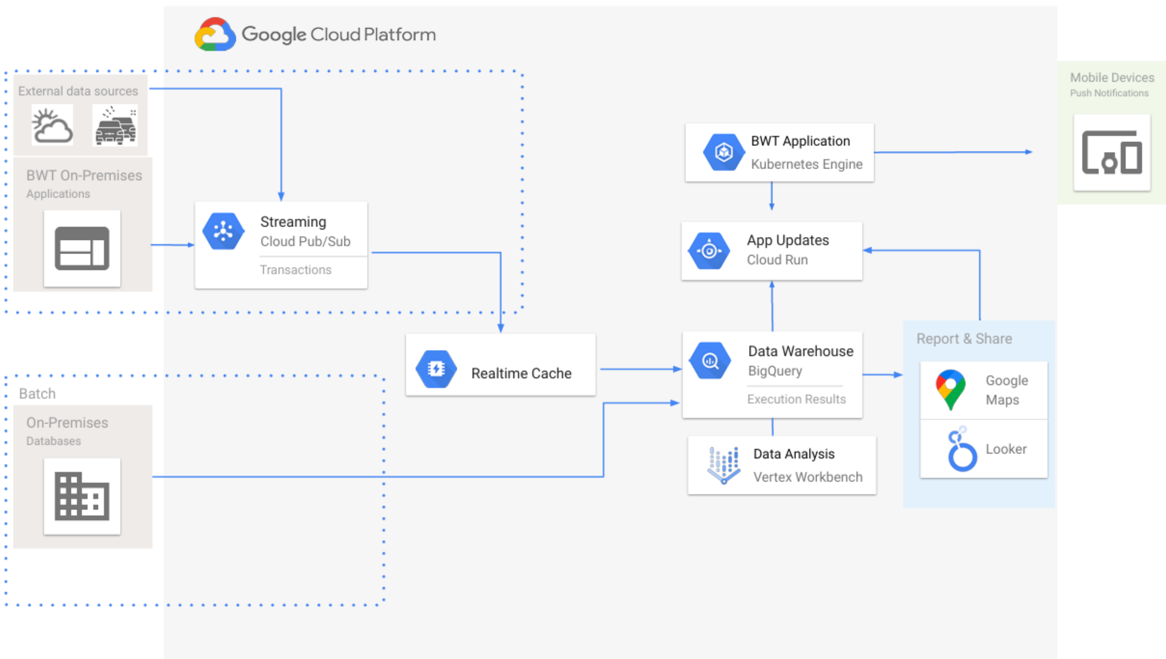


Figure 2. Architecture of the BWT App Leveraging Google Cloud Platform for Real-Time Data Streaming from External Sources to the Border Data Warehouse, Enabling Accurate BWT Predictions and Advanced Data Analysis

2.2. Key Components of the ABIS System Architecture

Figure 3 shows the key components of the ABIS at a very high level. It consists of the following sub-systems. A detailed architecture diagram along with the data flow between sub-systems is given in Figure 4.

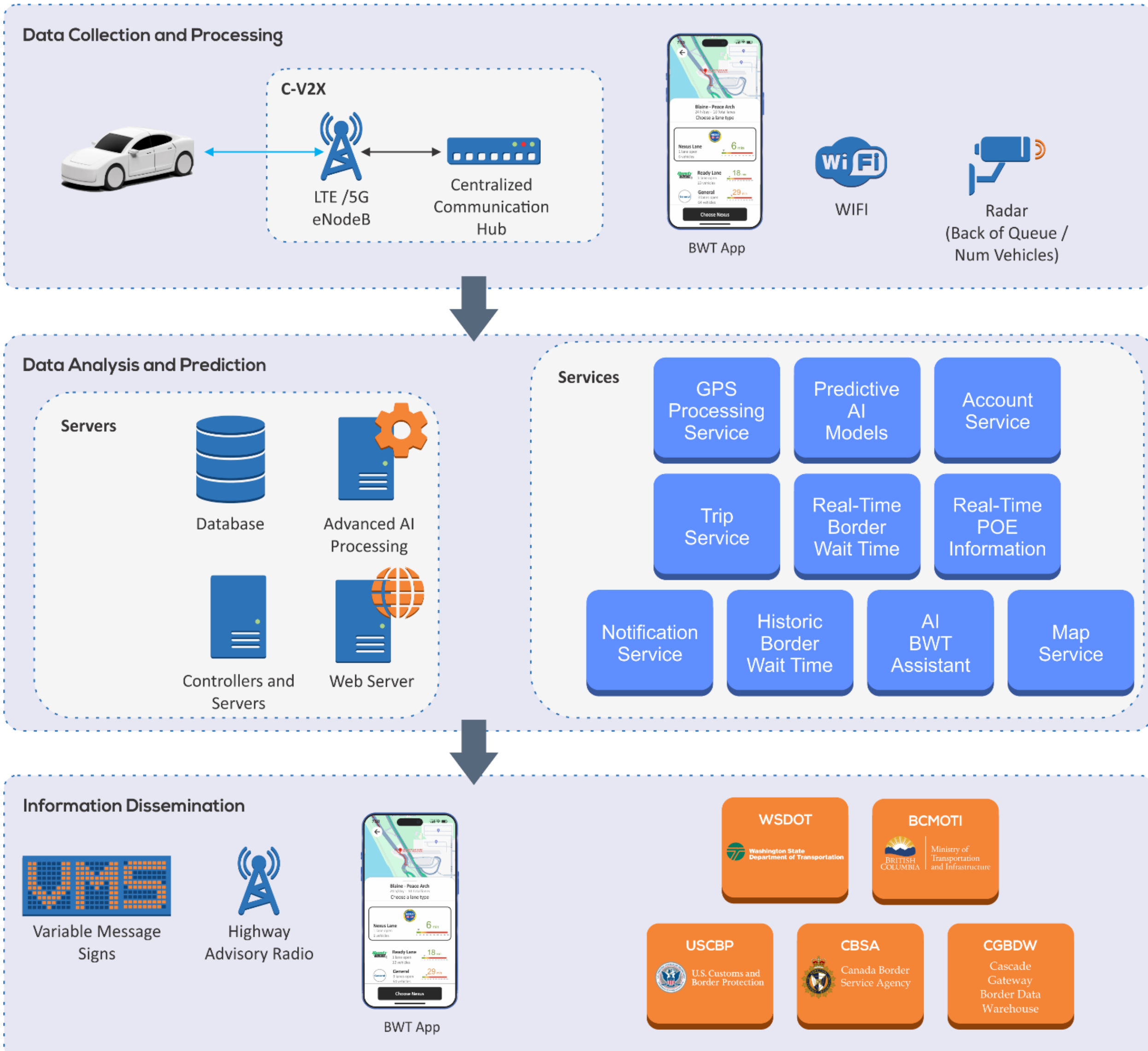


Figure 3. ABIS Key Components

2.2.1 Data Collection and Processing

C-V2X (Cellular Vehicle-to-Everything): This evolving (in terms of technology maturity, infrastructure and standardization) technology enables communication between vehicles, infrastructure, and pedestrians. In the context of border wait times, C-V2X would be used to track vehicle movement, location, identify congestion points, and estimate wait times based on traffic density and vehicle location. The provision is made in the proposed ABIS architecture for incorporating this emerging technology.

Radar Detection System: This device is used to measure the number of vehicles in the queue by lane type and the location of the back of the queue to develop delay algorithms. Note that radar detection is just one type of vehicle detection technology that could be deployed with the ABIS; as part of the detailed design, vehicle detection technologies will be further evaluated for technological maturity and technical relevance/applicability.

Bluetooth/Wi-Fi System: The Bluetooth/Wi-Fi system determines border wait time by identifying vehicles when they join the back of the queue, and reidentifying them upon arrival at the primary inspection. This is accomplished by reading the Media Access Control (MAC) addresses of mobile devices in the vehicles.

GPS Processing Service: Using the BWT App downloaded on the travelers' mobile devices, this component processes GPS data from the vehicles to determine their location and speed.

Centralized Communication Hub: This is the central point where data from the sources listed above is collected and processed. This hub can be in the form of cloud services or on an agency's premises. It aggregates information from C-V2X, radar, Bluetooth/Wi-Fi, GPS, and other subsystems to create a comprehensive picture of the border crossing situation.

Cascade Gateway Border Data Warehouse: This is the existing repository of historical BWT data that has been archived since 2007. The historic data will also be used for prediction. The ABIS will continue to archive data in this data warehouse.

2.2.2 Data Analysis and Prediction

Generative Artificial Intelligence (AI) Application Programming Interface (API): This component utilizes artificial intelligence to analyze traffic patterns, historical data, and real-time information to predict wait times. It can identify trends, anomalies, and potential issues that may impact wait times.

Predictive AI Models: These models use historical wait time data and real-time information to forecast future wait times. These self-learning models can use several techniques to avoid potential bias in the data and algorithms over a period of 3-6 months to reduce variance between observed and predicted wait times using accuracy metrics that include the following:

- Mean Absolute Error (MAE): Measures the average absolute difference between predicted and actual wait times.
- Mean Squared Error (MSE): Calculates the average squared difference between predicted and actual wait times.
- Root Mean Squared Error (RMSE): The square root of MSE, providing a more interpretable error metric.

This results in reliable and more accurately predicted travel times to help travelers plan their trips and border authorities manage traffic flow more effectively.

2.2.3 Information Dissemination

Web and App Platforms: These user-friendly interfaces provide real-time and predicted wait time information to travelers. It allows users of the web and the mobile app to access data, plan their trips, and get notifications about wait times. The app will provide real time information while en route, if conditions change.

Existing Traveler Information Systems: This includes existing variable message signs, highway advisory radio, websites, etc. The ABIS will integrate with these existing systems to provide travelers with wait time information.

BWT App: The dedicated BWT App provides the public-facing user interface to the system. Users can use the app to see real-time wait times, plan trips in the future, and receive navigational assistance.

2.2.4 System Architecture

Figure 4 shows the overall architecture of the ABIS system with its various components, field devices, and agency interfaces.

Table 1 provides the data flow between different architecture components and stakeholder agencies' traffic management centers.

Table 1. Data Content and Flow between Architecture Components and Stakeholder Agencies

Component	Type of Data	Receiving Component	Communication Method
Field Components (Bluetooth/Wi-Fi Readers, Radar Detection System)	Vehicle identification based on MAC address of devices inside the vehicle.	BWT Server	TCP/IP (TLS)
	Back of queue when in the radar detection range and vehicle count.	BWT Server	TCP/IP (TLS)
C-V2X (Centralized Communication Hub)	C-V2X Vehicle identification	BWT Server	TCP/IP (TLS)
Border Crossing Component (Controllers, Servers, AI Processing)	Wait time information	BWT Database	HTTPS/SOAP/REST
		Existing Traveler Information Systems (e.g., HAR, DMS/VMS, etc.)	TCP/IP (TLS)
Web Platform Component (Databases, Web Server, Web Portal)	Wait time information/ status/historical data	Web Platform	HTTPS/SOAP/REST
		BWT Database	HTTPS/SOAP/REST
Web Service API Component	Wait time information/ status/historical data	Stakeholder Agencies	HTTPS/SOAP/REST
		BWT App	HTTPS/SOAP/REST
External Services	Wait time information/ status/historical data/ trip information/traffic information	External Services	HTTPS/SOAP/REST

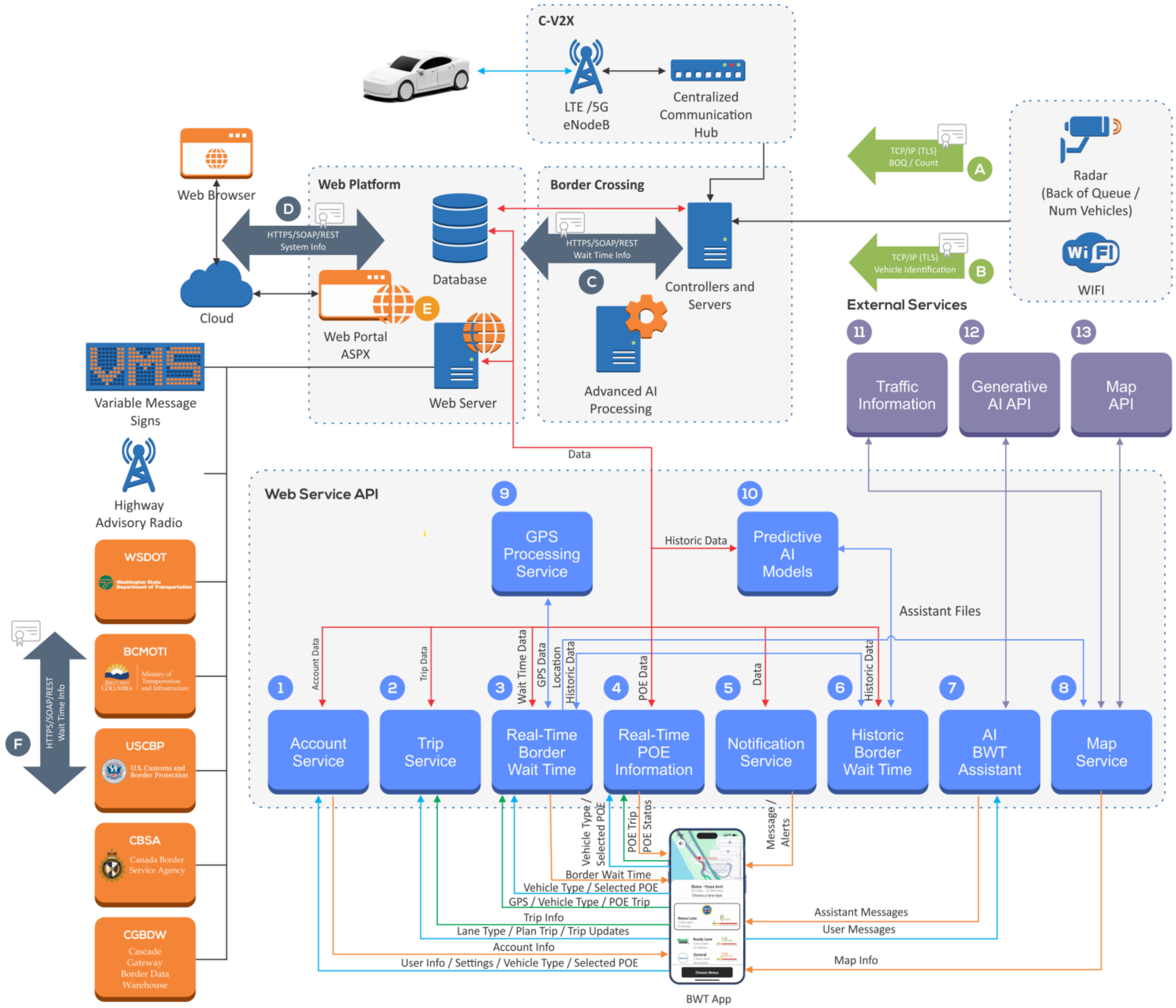


Figure 4. ABIS Functional Architecture Data Flow Diagram

2.2.5 Benefits

The benefits that the ABIS provides include:

- More reliable and accurate BWT for travelers and agencies
- Reduced wait times at the border
- Improved travel planning
- Increased convenience and efficiency
- Predictive and What-if scenario analysis for agencies
- More optimal use of resources
- More efficient and effective operation of ports of entry

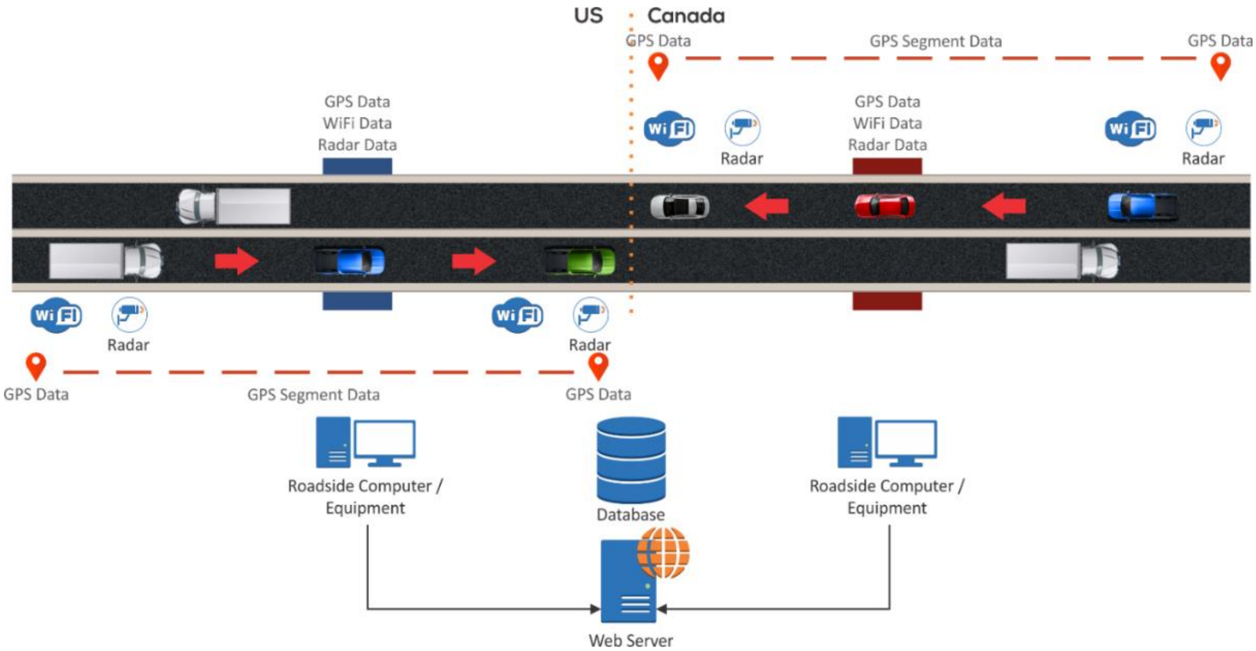


Figure 5. Conceptual Bluetooth/Wi-Fi and Radar Subsystems Architecture

3. SUBSYSTEM HARDWARE AND SOFTWARE COMPONENTS

The diagrams in this section show how all the parts, both current and future, are connected and interact with each other.

3.1. Subsystems

Bluetooth/Wi-Fi and radar detection data are collected and transmitted to the BWT app for processing and analysis. AI/ML models generate predictive wait times, which are then displayed on the app and shared with existing traveler information systems like VMS/DMS and HAR via the transportation agencies' traffic management centers. Communication infrastructure ensures reliable data flow between all components. Agency interfaces facilitate data exchange and collaboration. By integrating these subsystems, the BWT system delivers accurate, timely, and reliable wait time information.

3.1.1 Bluetooth/Wi-Fi and Radar Subsystems

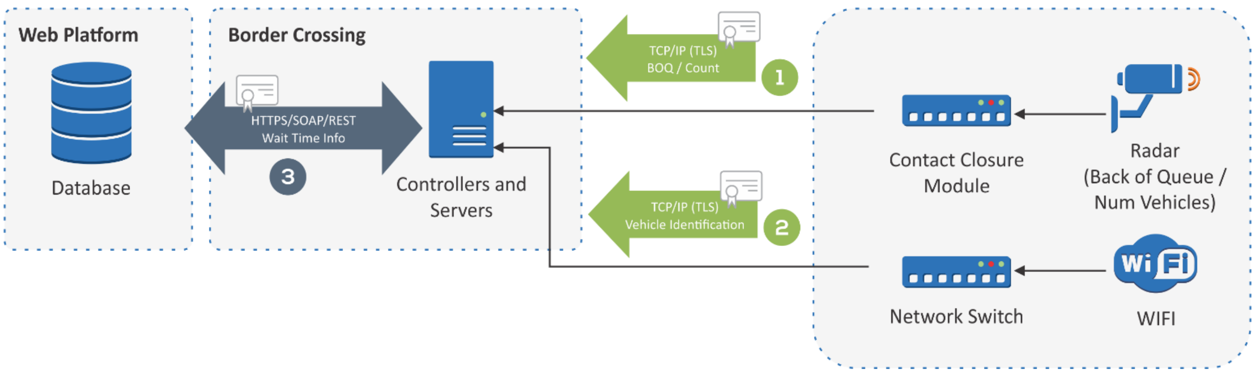


Figure 6. Communication Diagram for Bluetooth/Wi-Fi Readers and Radar Detection

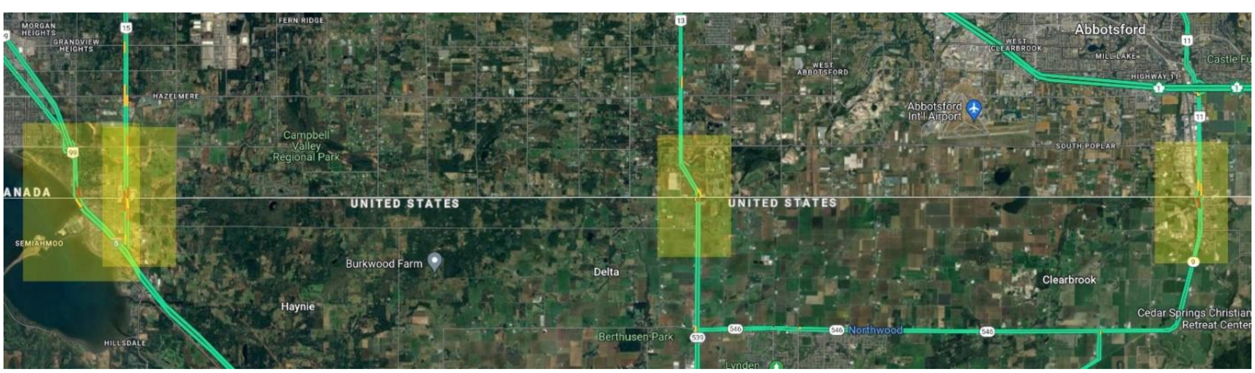


Figure 7. Project Boundary Limits (Highlighted) for the Four Ports of Entry

The Bluetooth/Wi-Fi reader sites play a crucial role in determining wait times for specific lane types such as NEXUS, Ready, and General lanes. By adjusting the height and signal strength of the readers, it is possible to target vehicles within particular lanes. Differentiating traffic by lane types allows for more reliable measurements of wait times.

While the initial plans presented in the sections below call for a certain number of installations, the final number may be adjusted based on the detailed design and engineering process during the implementation phase. Longer queues would require additional installation sites, and site-specific queuing characteristics may require some shifting of detector locations. For example, the northbound approach at Peace Arch periodically experiences bad backups past D Street; the first detector location could either be shifted, or the algorithm could be tweaked to account for this. This flexibility ensures that the system is optimally configured to meet the specific needs of the four ports of entry.

Figure 8. Radar Detection Field Installation Examples

The deployment sites for the Bluetooth/Wi-Fi and Radar subsystems are strategically placed to ensure power and communications infrastructure is available and that the readers can capture comprehensive data on both northbound and southbound traffic.

Bluetooth/Wi-Fi Sites: Bluetooth/Wi-Fi reader sites are positioned along the border crossings, starting at the international boundary. The naming convention for these sites is as follows. The same naming convention is used for all four POEs.

- WNB1: The first Bluetooth/Wi-Fi reader site on the northbound side, located near the border.
- WSB1: The first Bluetooth/Wi-Fi reader site on the southbound side, located near the border.
- The numbering continues sequentially moving away from the border.

Radar Detection Sites: Similarly, radar detection sites are numbered based on their proximity to the border. The same naming convention is used for all four POEs.

- RNB1: The first radar detection site on the northbound side, located near the border.
- RSB1: The first radar detection site on the southbound side, located near the border.
- The numbering continues sequentially moving away from the border.

Peace Arch/Douglas POE: Field Placement of Bluetooth/Wi-Fi and Radar Subsystems

Five Bluetooth/Wi-Fi sites and five radar detection sites are proposed for each approach for this POE.

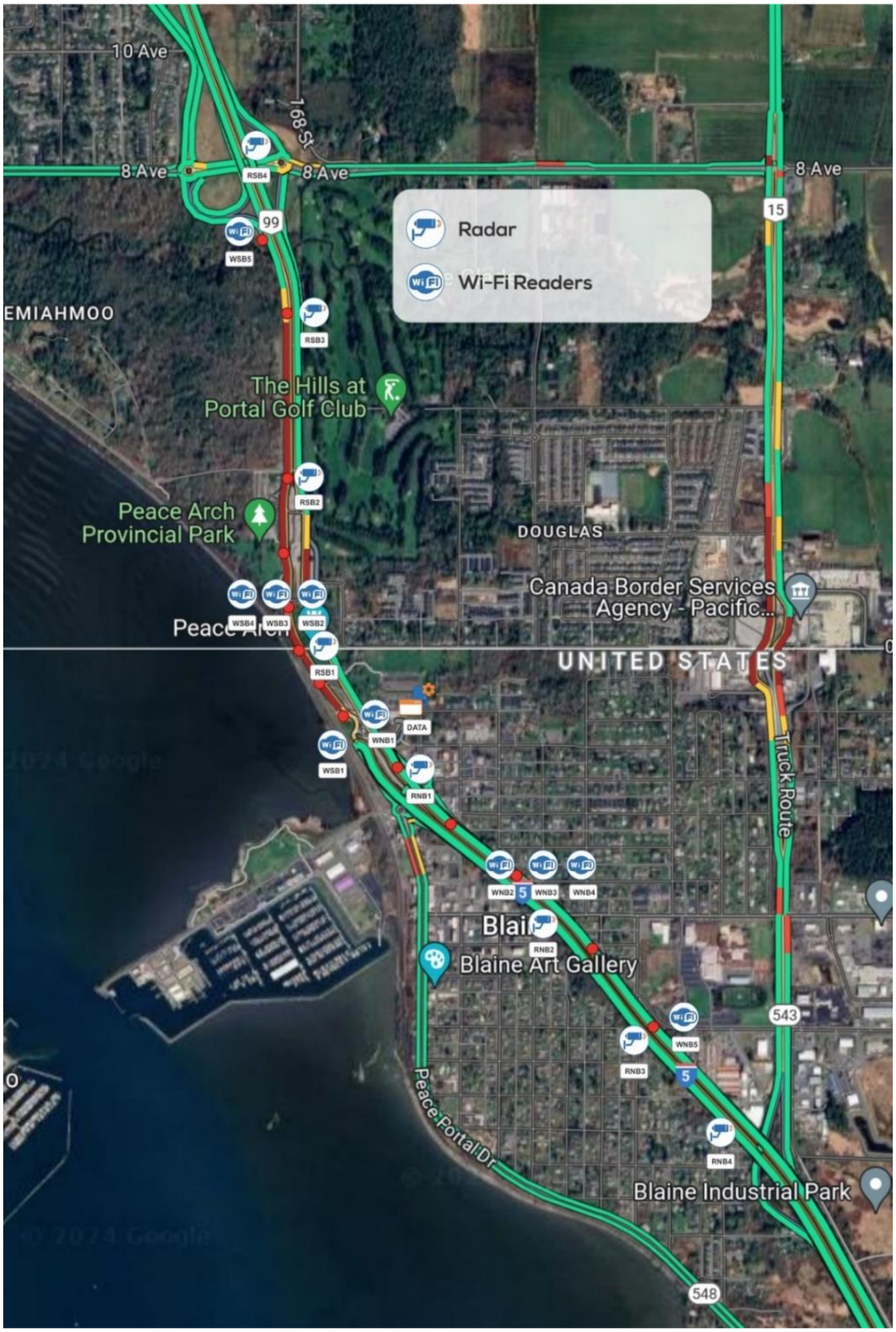


Figure 9. Preliminary Deployment Sites for Bluetooth/Wi-Fi and Radar Subsystems at the Peace Arch/Douglas POE

Pacific Highway POE: Field Placement of Bluetooth/Wi-Fi and Radar Subsystems

Five Bluetooth/Wi-Fi sites and five radar detection sites are proposed for each approach for this POE.

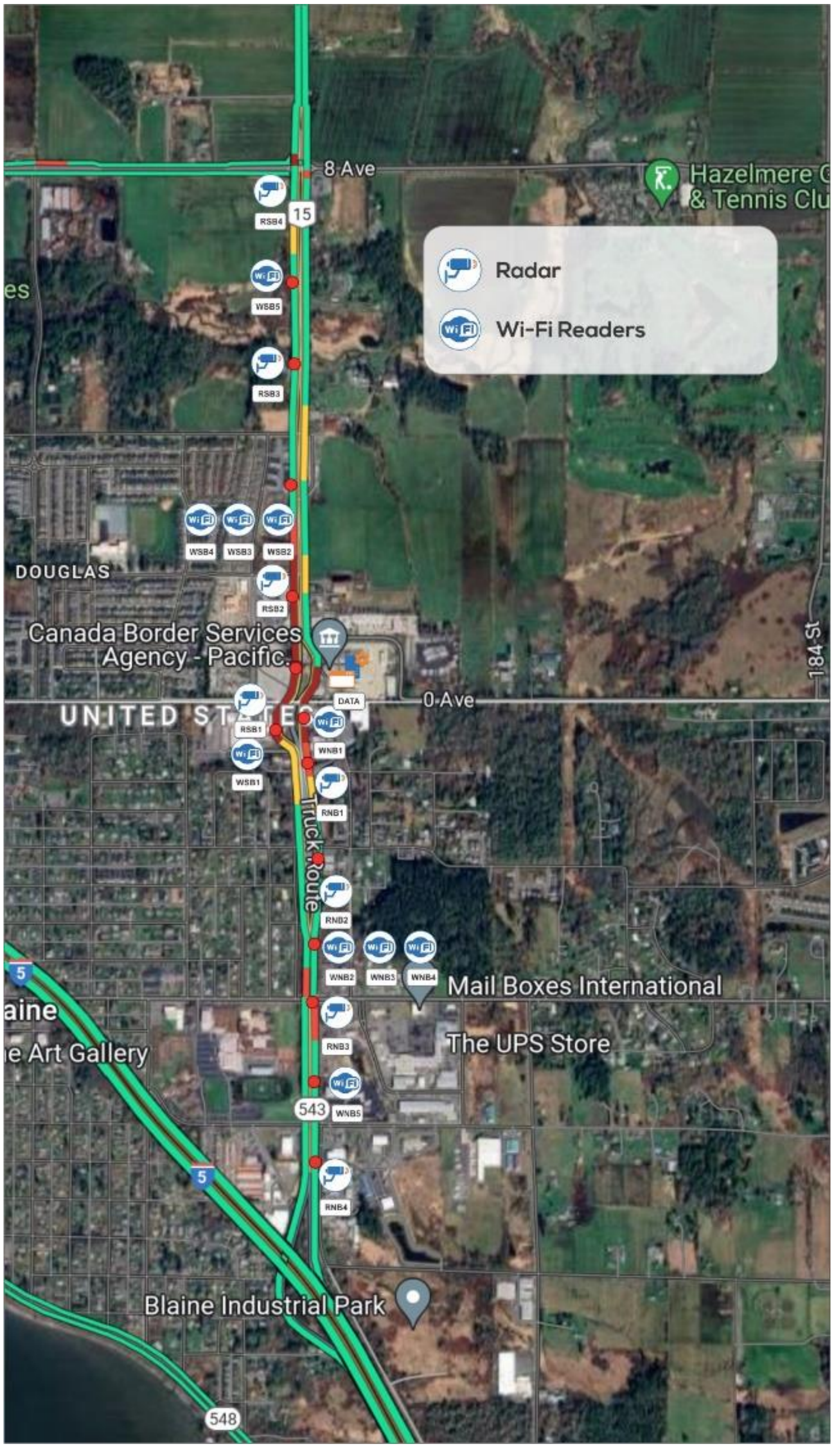


Figure 10. Preliminary Deployment Sites for Bluetooth/Wi-Fi and Radar Subsystems at the Pacific Highway POE

Lynden/Aldergrove POE: Field Placement of Bluetooth/Wi-Fi and Radar Subsystems

Four Bluetooth/Wi-Fi sites and four radar detection sites are proposed for each approach for this POE.

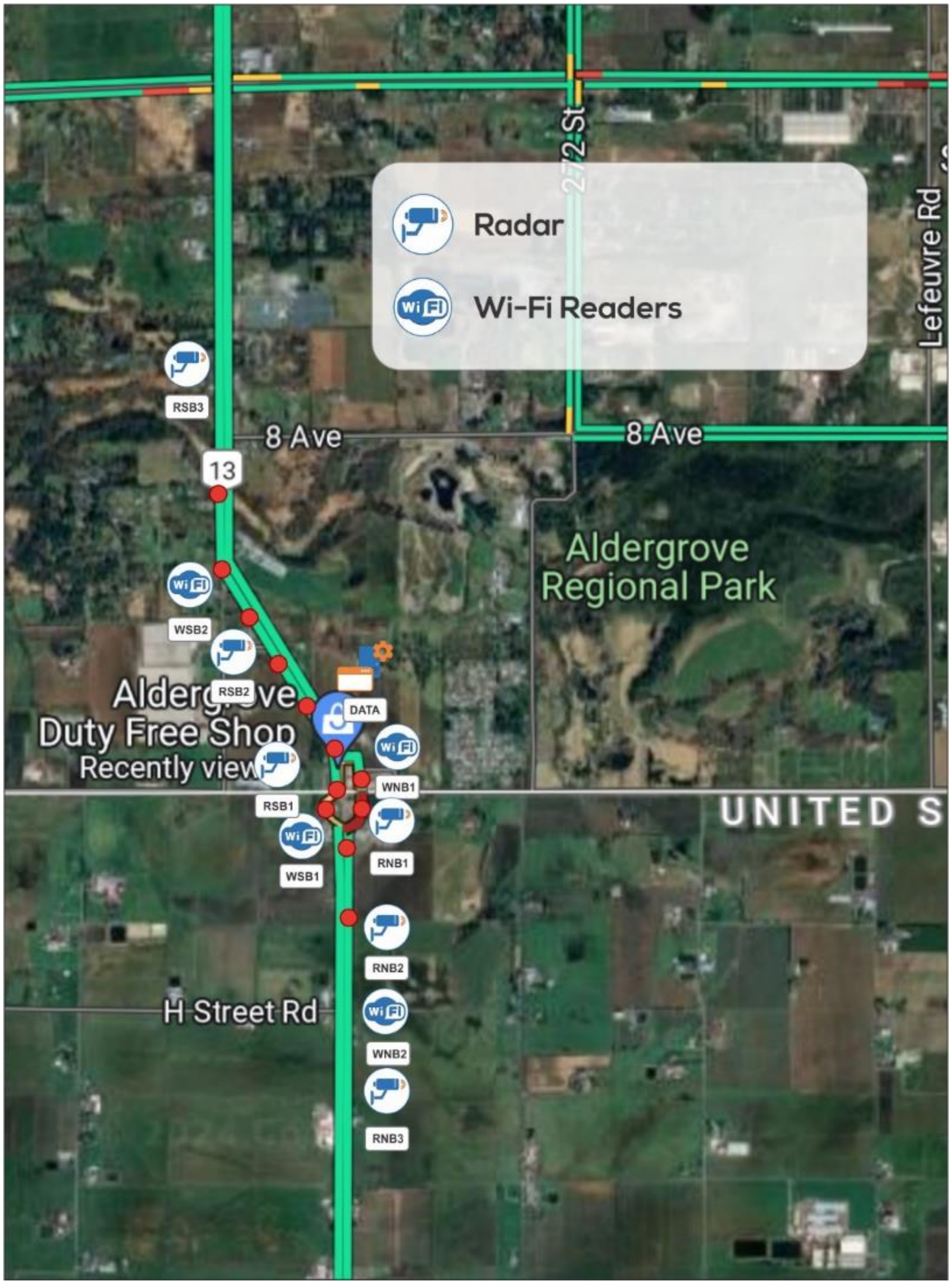


Figure 11. Preliminary Deployment Sites for Bluetooth/Wi-Fi and Radar Subsystems at the Lynden/Aldergrove POE

Sumas/Abbotsford-Huntingdon POE: Field Placement of Bluetooth/Wi-Fi and Radar Subsystems

Three Bluetooth/Wi-Fi sites and three radar detection sites are proposed for each approach for this POE.

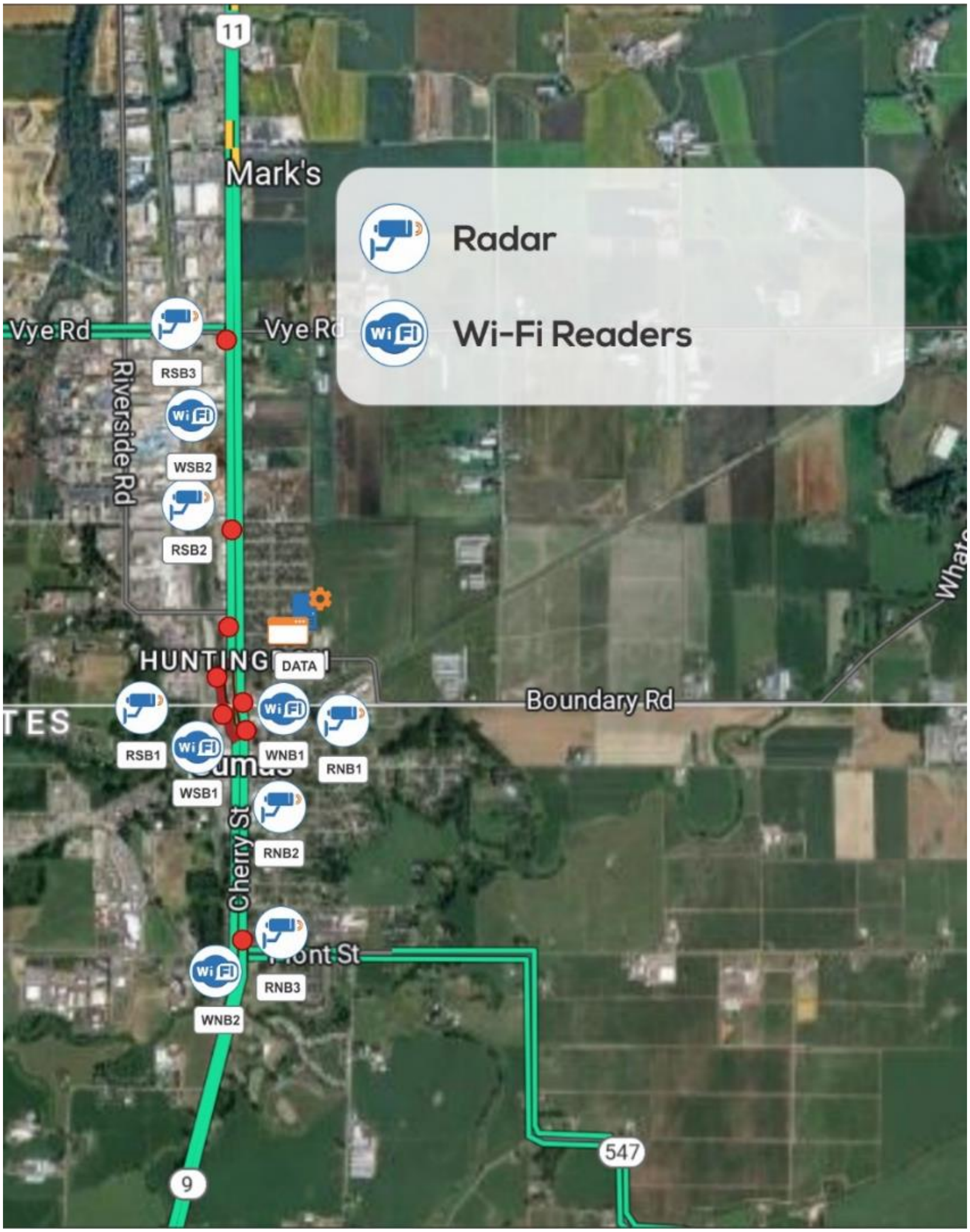


Figure 12. Preliminary Deployment Sites for Bluetooth/Wi-Fi and Radar Subsystems at the Sumas/Abbotsford-Huntingdon POE

Table 2. Preliminary Bluetooth/Wi-Fi and Radar Site Deployment Summary

Port of Entry	Northbound Bluetooth/Wi-Fi Sites	Southbound Bluetooth/Wi-Fi Sites	Northbound Radar Sites	Southbound Radar Sites
Peace Arch/Douglas	5	5	5	5
Pacific Highway	5	5	5	5
Lynden/Aldergrove	4	4	4	4
Sumas/Abbotsford-Huntingdon	3	3	3	3
Total Sites	***17***	***17***	***17***	***17***
Grand Total	**34**		**34**	

3.2. BWT App

The following diagrams illustrate the movement of data between the app, the central server, and external services. Using diagrams with color-coded arrows, this section visually depicts how user-generated data, automatic data from the app, responses from services, and internal server data flow within the BWT App ecosystem. **Blue lines denote user-generated data sent from the app to services, green lines represent automatic data transmission from the app to services (such as GPS data), orange lines indicate responses or messages sent from services to the app, and red lines depict data exchange within the server**, including communication between services and the central database. Blue boxes represent services running on the central server, while purple boxes denote external services integrated into the BWT system.

3.2.1 Registration

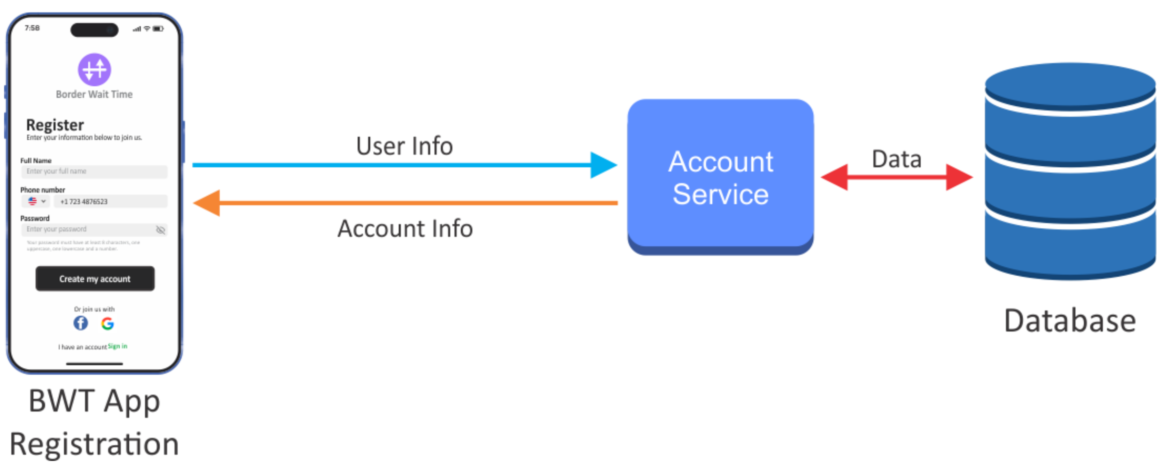


Figure 13. BWT App – Registration Module

The registration module allows users to create an account within the app. When the user submits their information, the app sends this data to the Account Service. The Account Service then communicates with the central database to create the account and store the user's information. Once the account is created, the service sends back the account details to the app, completing the registration process.

3.2.2 Settings

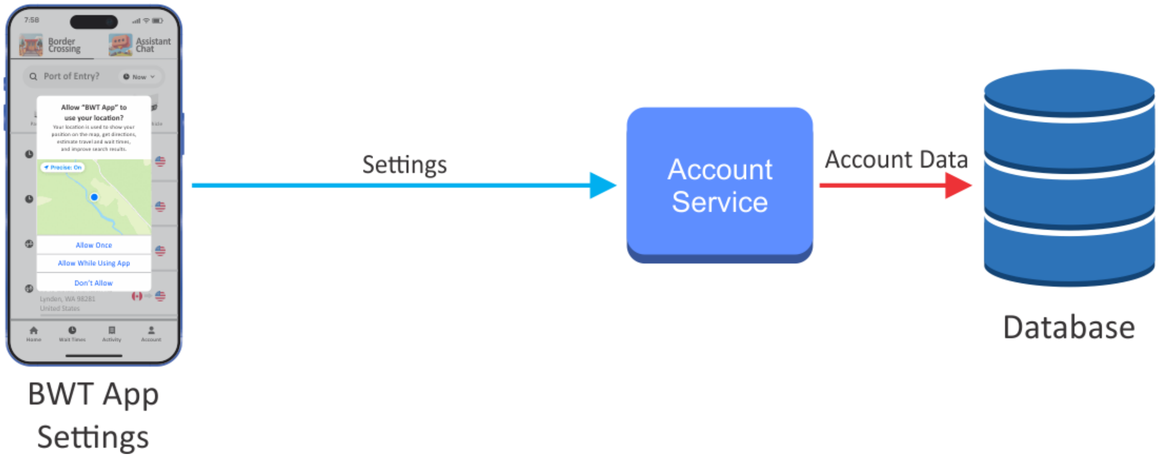


Figure 14. BWT App – Settings Module

The settings module enables users to configure their preferences, such as allowing GPS tracking. When the user updates their settings, the app sends these settings to the Account Service. The Account Service then stores the updated settings in the user's account data within the central database, ensuring that the user's preferences are saved and can be applied throughout the app.

3.2.3 POE Selection

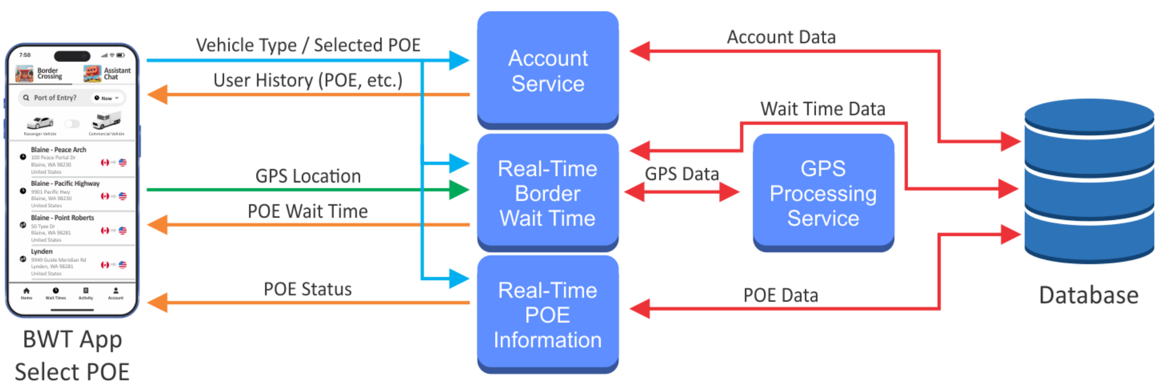


Figure 15. BWT App – POE Selection Module

In the POE Selection module, users can select their preferred lane type (i.e., NEXUS, Ready, General, and trucks) and desired border crossing point. The app sends this information, along with the user's GPS location, to the Account Service, Real-Time Border Wait Time Service, and Real-Time POE Information Service. These services interact with the central database to retrieve relevant data. The Account Service provides the user's history, the Border Wait Time Service returns current wait times, and the POE Information Service supplies the status of the selected POE.

3.2.4 Start Trip

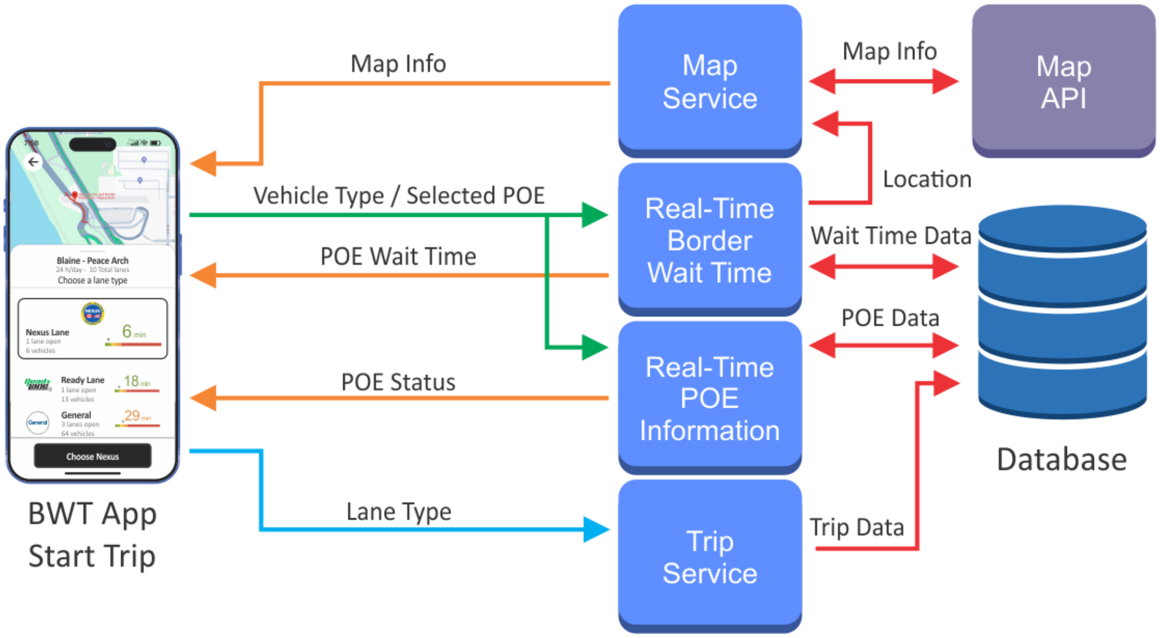


Figure 16. BWT App – Start Trip Module

The Start Trip module facilitates trip initiation. The app sends the selected vehicle type and POE to the Border Wait Time Service and the POE Information Service, and the selected lane type to the Trip Service. These services retrieve and store relevant trip information in the database. Additionally, the Map Service interacts with a Map API to obtain map data, which is then provided to the app. The Border Wait Time Service returns the current wait times at the POE, while the POE Information Service provides the status of the POE.

3.2.5 Track Trip

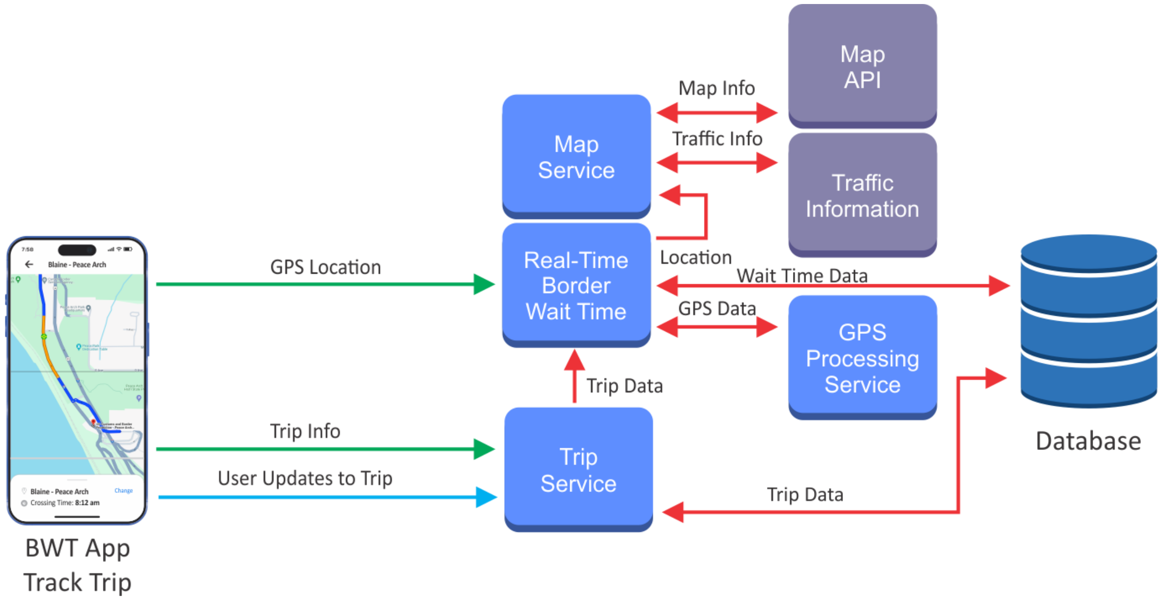


Figure 17. BWT App – Track Trip Module

In the Track Trip module, the app sends the user's GPS location to the Border Wait Time Service, which then communicates with the Map Service, Map API, and Traffic Information API to provide real-time travel updates. The Border Wait Time Service also stores and retrieves data from the database. Concurrently, the app sends trip information and any user updates to the Trip Service, ensuring that the trip details are continuously monitored and updated.

3.2.6 Messaging

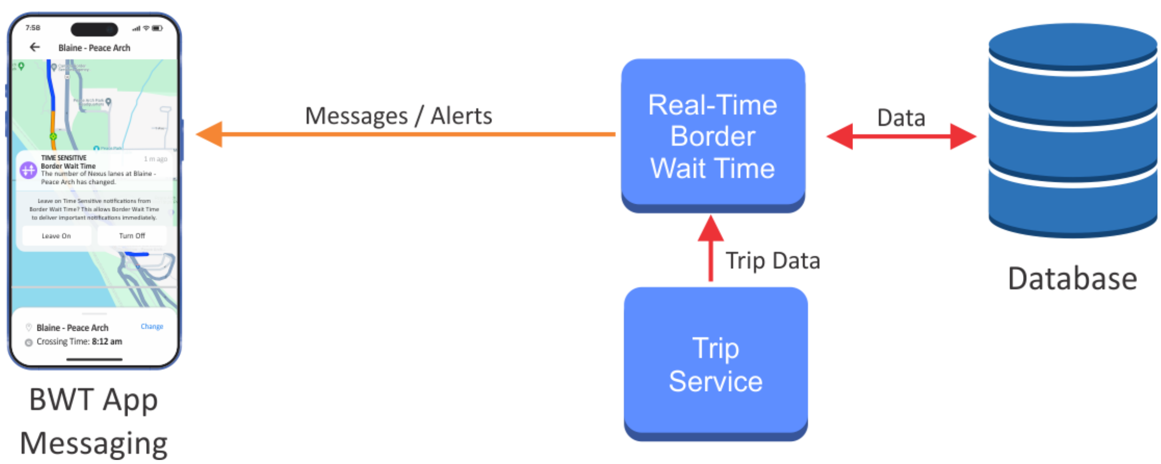


Figure 18. BWT App – Messaging Module

The Messaging module allows users to receive notifications and alerts during their trip. The Border Wait Time Service communicates with the Trip Service and the central database to generate relevant messages. These messages, including important alerts, are then sent to the app to keep the user informed throughout their journey.

3.2.7 Plan Trip

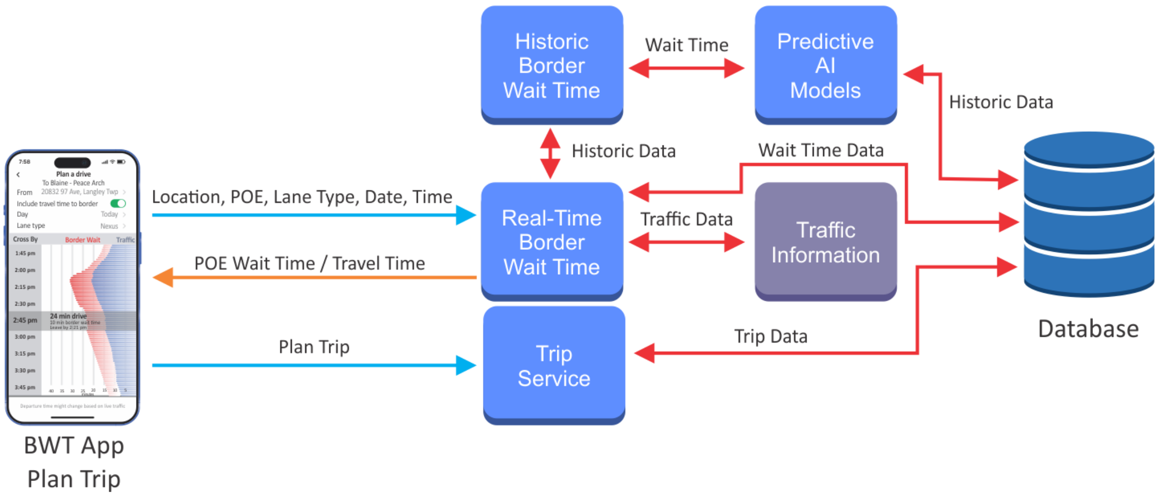


Figure 19. BWT App – Plan Trip Module

The Plan Trip module assists users in organizing their trips. The app sends location, selected POE, lane type, and intended crossing time and date to the Border Wait Time Service. The service connects to the central database, the Historic Border Wait Time Service, and the Traffic Information API to calculate and return the predicted wait time at the POE and the estimated travel time. The Historic Border Wait Time Service also consults the Predictive AI Models Service, which leverages historic data from the database. Once the trip is planned, the app sends the final trip details to the Trip Service for storage and future reference.

3.2.8 AI Assistant

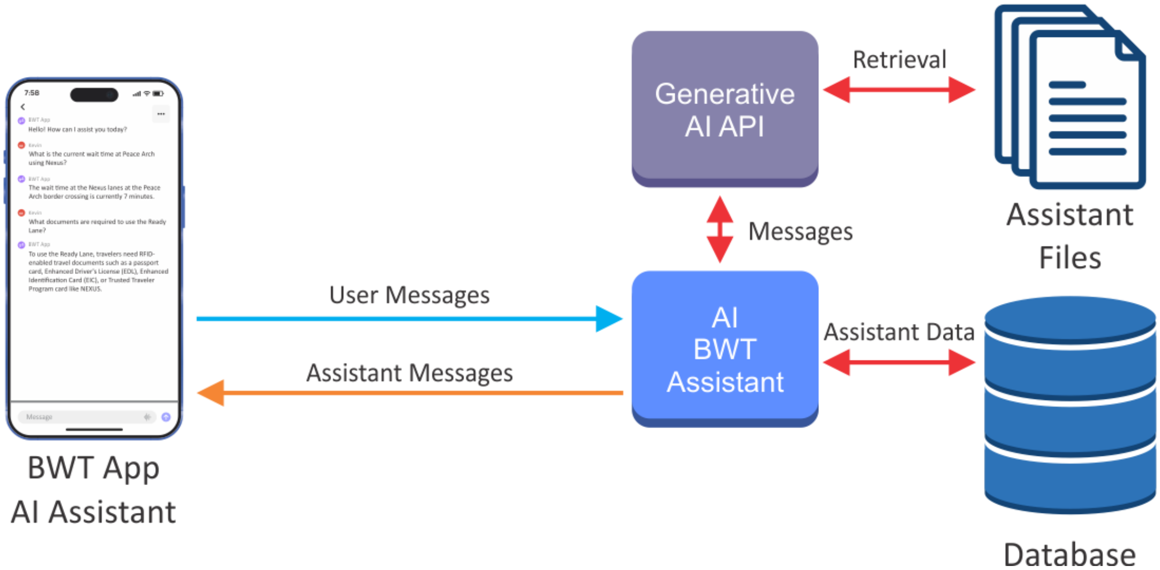


Figure 20. BWT App – AI Assistant Module

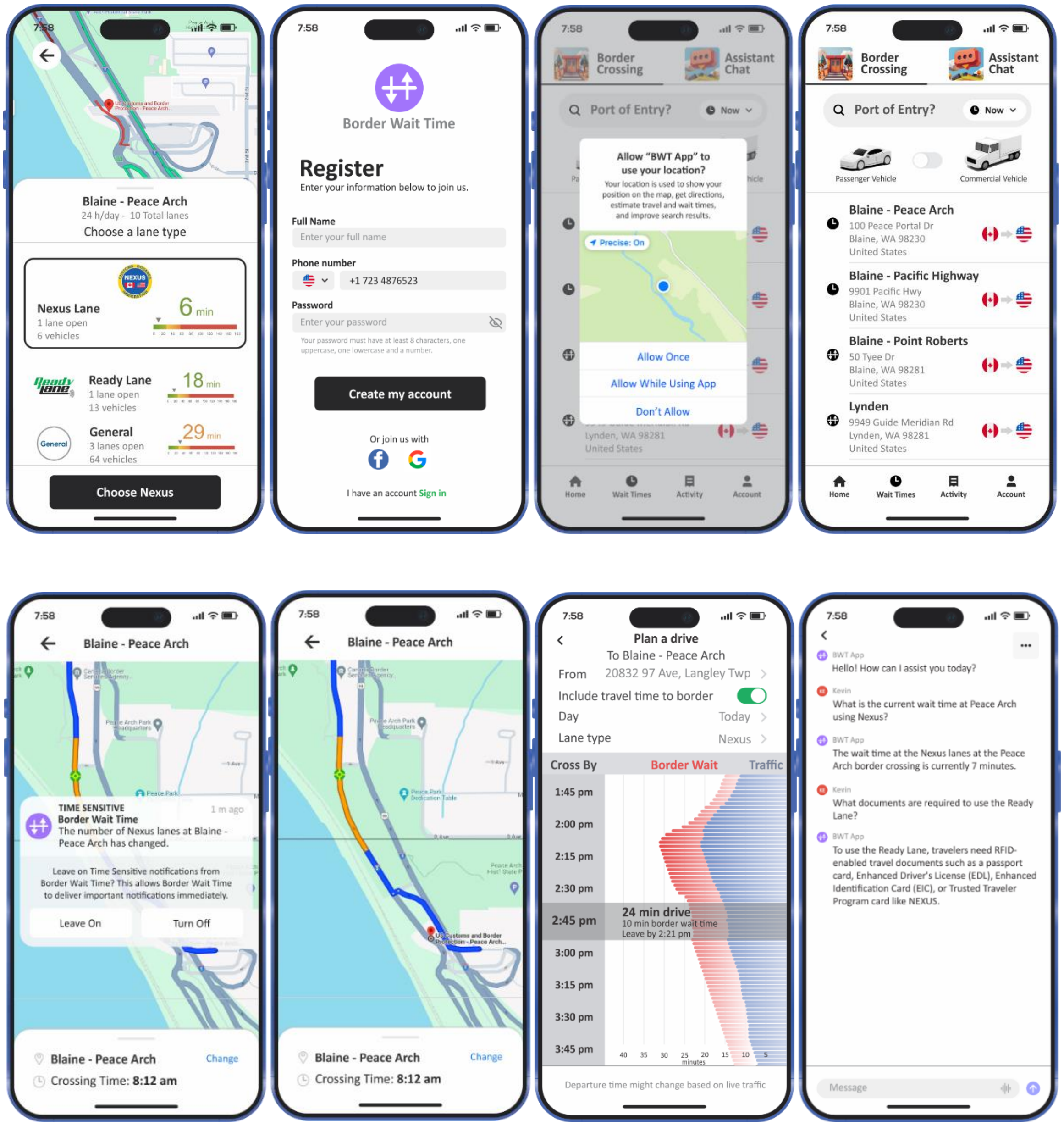
The AI Assistant module allows users to ask questions about border wait times by lane type or time of crossing. The app sends these questions to the AI BWT Assistant Service, which queries the database and consults AI knowledge stored in Assistant Files. The AI Assistant then processes this information and provides relevant responses back to the app, assisting the user with their inquiries.

3.2.9 Requirements Traceability Matrix

This traceability matrix links the requirements to the app modules, ensuring that key functionalities (user interaction, GPS tracking, trip monitoring, and data collection) are mapped and implemented to meet the overall system goals of providing accurate BWT and improving user experience. The requirements traceability matrix can be found in Section 4.1.2.

3.2.10 Proposed Graphical User Interface for Mobile Application

The following sequential (left to right) sample screens provide how the users can interact with the BWT mobile application and request the information they are seeking in real time.



3.3. BWT Prediction

The following sections detail the advanced tools employed for data aggregation, processing, and prediction. These state-of-the-art, commercial-off-the-shelf solutions from Google, a market leader in technology, have been selected for their proven reliability and efficiency. Their ubiquitous nature and user-friendly interfaces make them accessible to a wide range of users, ensuring that complex data tasks can be managed with ease.

Moreover, the seamless integration of these tools with Google Maps and Google Cloud infrastructure provides a cohesive and powerful data ecosystem. This integration not only simplifies the workflow but also enhances the capability to generate accurate and timely predictions. By leveraging Google's advanced technologies, the system's high-level design ensures robust data handling and insightful analytics, essential for informed decision-making and strategic trip planning for all border crossers and stakeholder agencies.

3.3.1 BigQuery: The Data Foundation

BigQuery can be compared to a vast digital warehouse. It stores a wealth of information related to border crossings, both historical and real-time. This includes past wait times, traffic patterns, current vehicle counts, and even data from external sources like weather reports and news feeds. By consolidating this information, BigQuery creates a single source of truth for understanding border activity.

- **Data Storage**: BigQuery can handle massive amounts of structured and semi-structured data related to border crossings. This includes:
  a. Historical Data: Years of recorded border crossing volumes, wait times, traffic patterns, etc.
  b. Real-Time Data: Up-to-the-minute updates on current traffic conditions, vehicle counts, and sensor data from border crossings.
  c. External Data: Information from weather services, event calendars, news feeds (for accidents or road closures), and other relevant sources that could impact border traffic.
- **Data Processing**:
  a. Aggregation: Combining data from multiple sources and time periods to calculate average wait times, peak hours, and trends.
  b. Transformation: Cleaning and organizing raw data into a format suitable for analysis and modeling.
  c. Querying: Allowing analysts/engineers to ask complex questions of the data to uncover insights and patterns.

3.3.2 Looker Studio: Turning Data into Actionable Insights

Looker Studio serves as the visual storyteller. It transforms raw data from BigQuery into user-friendly dashboards. These dashboards can display real-time wait times at different border crossings, historical trends, and even heatmaps showing congestion areas. These insights are invaluable for both travelers planning their trips and border agency officials managing resources.

- Dashboard Creation: Looker Studio provides a drag-and-drop interface for building interactive dashboards that display real-time and predicted wait times. These dashboards can include:
  a. Line Charts: Showing wait time trends over time.

b. Bar Charts: Comparing wait times at different border crossings or times of day.

c. Heat Maps: Visualizing traffic congestion around border areas.

d. Tables: Displaying detailed wait time data for each crossing.

e. Geo Maps: Integrating with Google Maps to show wait times overlaid on maps of border regions.

- Customizability: Dashboards can be tailored to the needs of different stakeholders:

    a. Public-Facing Dashboards: Simple, easy-to-understand displays for travelers.

    b. Official Dashboards: More detailed, with drill-down capabilities for border officials to analyze trends and allocate resources.

    c. Real-Time Updates: Looker Studio can be configured to refresh data automatically, ensuring that the displayed wait times are always up to date.

3.3.3 Vertex AI: The Brain Behind Data Analysis and Prediction

Vertex AI is the brains of the operation. It leverages machine learning models to analyze the data stored in BigQuery. By identifying patterns in historical data, real-time traffic conditions, and external factors, Vertex AI can predict border wait times with high accuracy.

- Model Development: Vertex AI will be used to develop machine learning models that predict border wait times. These models would consider:

    a. Historical Patterns: How wait times have varied historically based on time of day, day of week, season, holidays, special events, etc.

    b. Real-Time Inputs: Current traffic conditions; inputs from Bluetooth/Wi-Fi Readers, radar detection, and other field devices; weather data; and other factors that could affect wait times.

    c. External Data: Events happening near the border, road closures, accidents, etc.

- Model Deployment: Once a model is trained and tested, it can be deployed on Vertex AI and on the cloud to make predictions in real time that can include 15-, 30-, 45- and 60-minute intervals. The model can also predict in hourly intervals after training.
- Model Monitoring: Vertex AI can continuously monitor the model's performance and accuracy, alerting stakeholder agencies if the model needs to be updated, if accuracy falls below 85%, for example.

3.3.4 Google Maps Platform Integration: Real World Context

Google Maps Platform integrates real-time traffic data into the equation. It provides insights into current traffic speeds and congestion levels, both around border crossings and on nearby roads. This information feeds directly into the machine learning models mentioned above, further refining their accuracy.

- Real-Time Traffic Data: Google Maps continuously collects data on traffic speeds and congestion levels from various sources (GPS devices, smartphones, etc.). This data can be used:

    a. Directly: To estimate current wait times based on the traffic flow around border crossings.

    b. As Input: To feed into the machine learning models on Vertex AI, improving their accuracy.

- Geocoding and Geolocation: These capabilities allow for precise mapping of border crossings and wait time data. This is crucial for:
    a. Displaying Wait Times: Showing users reliable wait times at various ports of entry
    b. Routing and Navigation: Helping travelers find the fastest or least congested route to the border.

3.3.5 Automated Reports

Google Cloud can generate automated reports tailored to the needs of different stakeholders. Travelers might receive simple email alerts about estimated wait times, while border officials could receive comprehensive reports analyzing trends and identifying areas for improvement.

3.3.6 Summary

By combining the power of BigQuery, Looker Studio, Vertex AI, and Google Maps Platform, public agencies can create a transparent, efficient, and data-driven border management system. This translates to shorter wait times, better-informed travelers, and optimized resource allocation for a smoother border crossing experience for everyone.

3.4. Existing Traveler Information Systems

3.4.1 Real-Time Information Dissemination

There are existing DMS/VMS and HAR along the approaches to the four ports of entry. These signs are controlled remotely from a central traffic management center, allowing for timely updates based on real-time data. HAR broadcasts audio messages over AM radio frequencies to travelers. These broadcasts provide detailed information about traffic conditions, border wait times, and other relevant travel advisories. The integration of these field devices, as well as existing websites and apps, with the ABIS and the corresponding traffic management centers ensures that travelers receive up-to-date information through both visual and auditory channels, enhancing their ability to make informed travel decisions. This includes the ability to push real-time wait time data by lane type directly to existing systems. This integration will comply with existing agency and ITS standardized communication protocols to ensure seamless data exchange. For VMS, the ABIS will send updated messages that reflect current border wait times, which will be displayed on the signs in near real-time. For HAR, the ABIS will provide updated audio messages that are broadcast to travelers, ensuring they receive the latest information as they approach the border.

3.5. Fiber Optic Communications

The northbound approach to the Lynden/Aldergrove POE is currently equipped with a wireless communications system. However, the system is ageing and is experiencing reliability issues. As such, the ABIS will replace this existing wireless communications connection with new fiber optic communications along SR 539/Guide Meridian Road, between H Street and Main Street, as indicated by the red line shown in the figure below. This includes approximately 3.9 miles of new conduit, pull boxes, cable vaults, fiber optic cabling, splice closures, fiber optic patch panels and switches, and other necessary equipment and accessories.

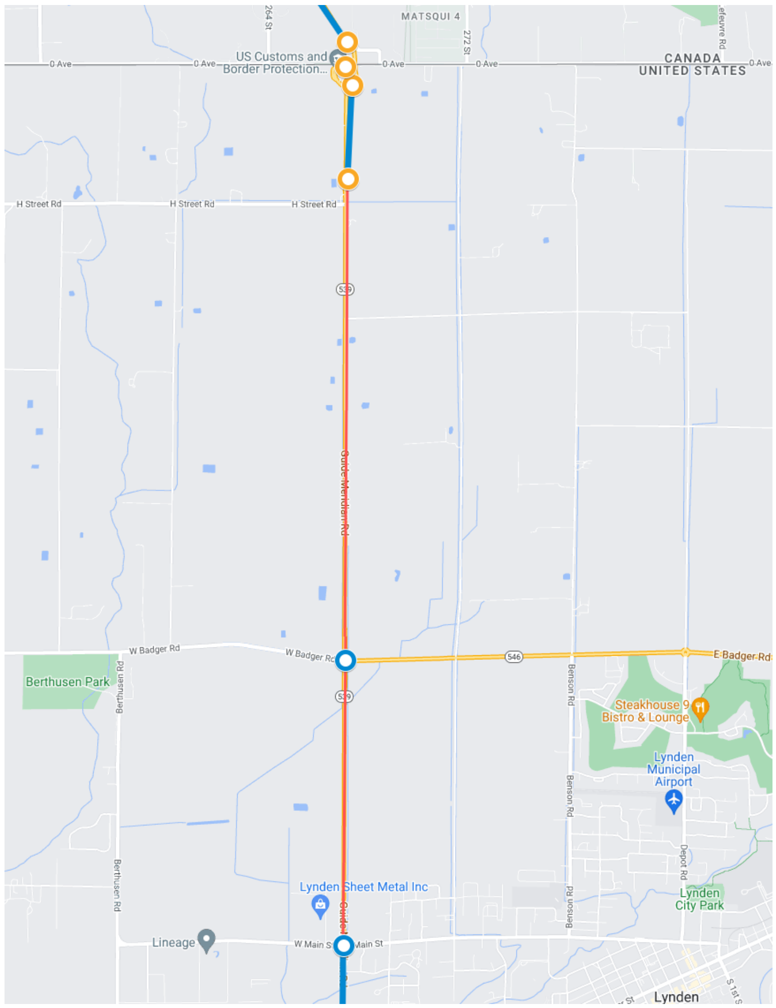


Figure 21. New Fiber Optic Communications System at Lynden/Aldergrove POE

3.5.1 Design Considerations

Design of the fiber optic communications system will be in accordance with the latest version of the WSDOT Northwest Region ITS Design Requirements. This is anticipated to include 1-36 Single Mode Fiber Optic (SMFO) cable within 2-2" Schedule 80 conduits, with pull boxes every 1,000 feet and cable vaults at splice points. This location is within a rural area, so it is anticipated that conduits can generally be trenched within softscape, outside of the traveled way.

4. NEEDS AND REQUIREMENTS

The ABIS is designed to address all stakeholder agency and user needs comprehensively, ensuring that no requirement is overlooked. User needs were systematically converted into functional requirements to guarantee that all agency requirements are comprehensively addressed. Many of the operational requirements were gathered during the project team's visit to the U.S.–Canada border and meeting with POE staff from Customs and Border Protection (CBP) and Canadian Border Service Agency (CBSA). We also gathered some of the agency's requirements from reviewing the literature and through discussions with WSDOT and BCMOTI, the owners, operators, and maintainers of the system. By carefully analyzing user feedback and aligning it with the goals and regulations of the border and local agencies, the high-level design ensures that the system functionalities not only meet user expectations but also comply with agency standards. This process ensures that every aspect of the ABIS is designed to enhance efficiency, accuracy, and user satisfaction, while maintaining compliance with necessary guidelines and protocols of the stakeholder agencies.

Effective requirements exhibit several key characteristics, as summarized below from the Systems Engineering Handbook:

- Specific: Clearly state what is needed without ambiguity.
- Measurable: Can be quantified and tested.
- Achievable: Realistic within the project constraints.
- Relevant: Directly related to the project goals.
- Time-bound: Include a timeframe for implementation when applicable.

Additionally, good requirements should be:

- Traceable: Linked to their source and other related requirements.
- Consistent: Not in conflict with other requirements.
- Complete: Fully describe the needed functionality.
- Verifiable: Can be confirmed through inspection, demonstration, or testing.

By clearly defining and balancing these user and agency requirements using the above criteria, the system can be designed to be both user-friendly and compliant with all necessary standards. This approach not only enhances user experience but also supports border agencies in managing and reducing wait times effectively.

Section 4.1.2 provides two traceability matrices, one for the ABIS that includes field devices, and the other for the BWT App.

4.1. Agency Interfaces

4.1.1 Technical Overview of Agency Interfaces in the Border Wait Time System

The integration of agency interfaces with the ABIS is a critical aspect that ensures seamless data exchange and communication between the BWT system and various border stakeholder agencies. The sections below provide a detailed technical explanation of how these interfaces are achieved.

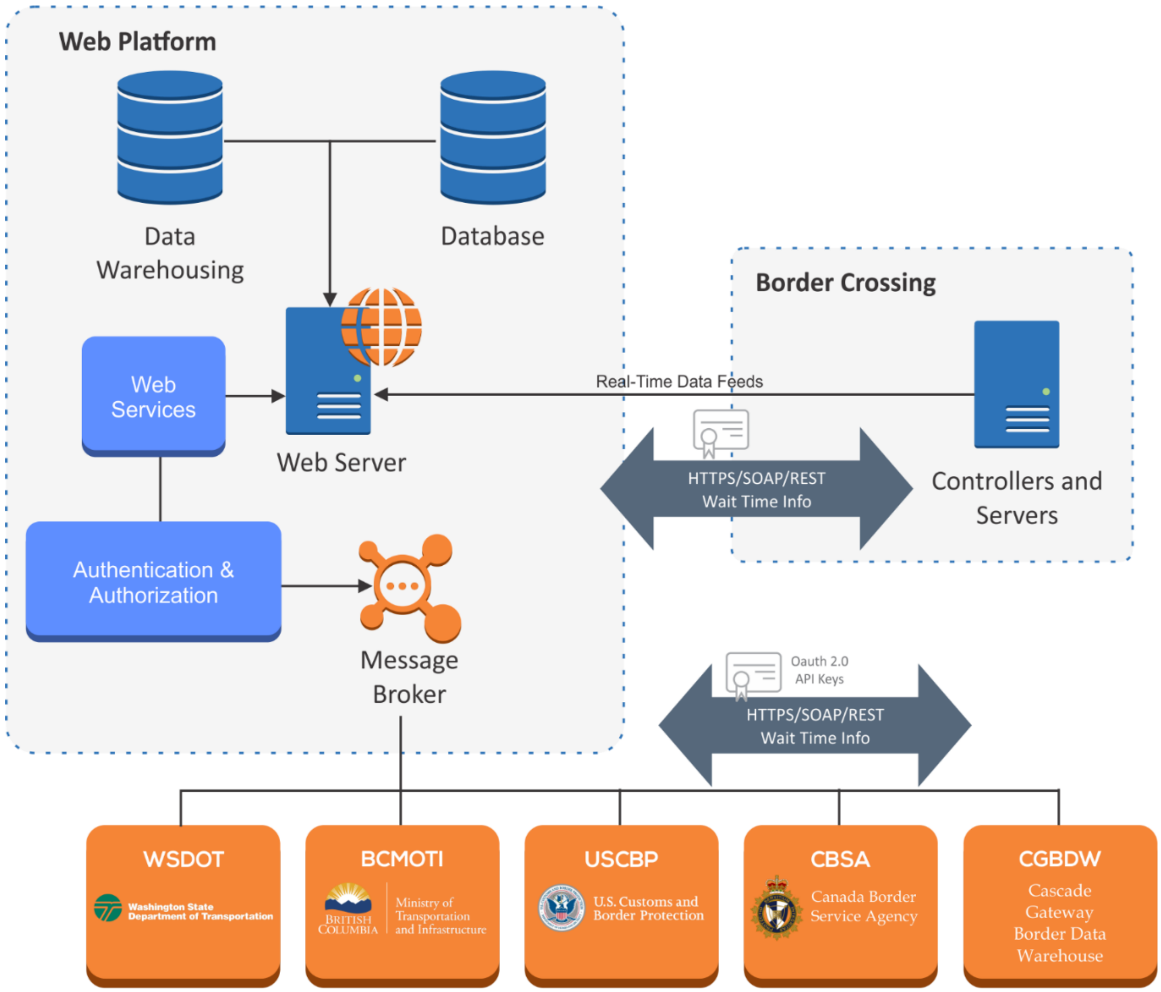


Figure 22. ABIS Data Interfaces

- Web Service API:
  a. RESTful APIs: The BWT system employs RESTful APIs to facilitate communication between the system and external agencies. These APIs allow for standardized HTTP methods (GET, POST, PUT, DELETE) to request and send data.
  b. Data Formats: JSON and XML are commonly used data formats for API responses and requests, ensuring compatibility and ease of parsing by different systems.
- Data Integration and Exchange:
  a. Real-Time Data Feeds: The system integrates real-time data feeds from various sources, including traffic cameras, weather services, and connected vehicle data. This data is processed and shared with agencies to provide up-to-date information.
  b. Secure Data Transmission: Data exchange is secured using HTTPS protocols, ensuring that all communications are encrypted and protected from unauthorized access.
- Middleware and Message Brokers:

a. Message Queues: Middleware components such as message brokers (e.g., RabbitMQ, Apache Kafka) are used to handle the asynchronous exchange of data between the BWT system and agency systems. This ensures reliable and scalable data transmission.

b. Data Transformation: Middleware services also handle data transformation, converting data into the required formats for different agency systems.

- Database Integration:

a. Centralized Database: A centralized database stores all collected data, which can be accessed by authorized agency systems. The database management system (DBMS) ensures data integrity and supports complex queries.

b. Data Warehousing: For historical data analysis and reporting, a data warehouse is used. This allows agencies to perform trend analysis and generate reports based on historical wait time data.

- Authentication and Authorization:

a. OAuth 2.0: The system uses OAuth 2.0 for secure authentication and authorization, allowing agencies to access data based on their roles and permissions.

b. API Keys: API keys are issued to agency systems to authenticate their requests to the BWT system, ensuring that only authorized entities can access the data.

- Interoperability Standards:

a. ITS Standards: The BWT system adheres to Intelligent Transportation Systems (ITS) standards, such as the National Transportation Communications for ITS Protocol (NTCIP), ensuring interoperability with other transportation systems.

b. Custom Protocols: Where necessary, custom protocols are developed to meet specific agency requirements, ensuring seamless integration and data exchange.

- Monitoring and Logging:

a. Real-Time Monitoring: The system includes real-time monitoring tools to track the performance and health of the interfaces. This helps in identifying and resolving issues promptly.

b. Logging and Auditing: Comprehensive logging and auditing mechanisms are in place to track all data exchanges and access, ensuring accountability and traceability.

- Benefits of Agency Interfaces:

a. Enhanced Decision-Making: By providing real-time and predictive wait time data, agencies can make informed decisions to manage border traffic more effectively.

b. Improved Coordination: Seamless data exchange ensures better coordination between different agencies, leading to more efficient border operations.

c. Scalability: The use of standardized APIs and middleware components allows the system to scale easily, accommodating additional agencies and data sources as needed.

d. Security and Compliance: Robust authentication, authorization, and encryption mechanisms ensure that data is protected, and the system complies with relevant regulations.

By leveraging these technical components and standards, the BWT system ensures that agency interfaces are robust, secure, and efficient, ultimately contributing to a more streamlined and effective border management process.

4.1.2 Requirements Traceability Matrix

The following sections include requirements traceability matrices that cover both the ABIS as a whole, and the BWT App. Note that these matrices are preliminary. They are based on the interviews with the stakeholder agencies, the project team's experience completing similar projects, and the high-level design, but will be expanded under each category during detailed design, including an expanded system acceptance test plan.

Requirements Traceability Matrix for the ABIS

The requirements traceability matrix for the ABIS, shown in Table 3, maps the preliminary system requirements, along with the corresponding Modules/Functionalities and traceability to the User Need(s) (See the Concept of Operations for a full of list of user needs: https://theimtc.com/wp-content/uploads/3-Concept-of-Operations.pdf) that generated the requirement. Each requirement will be verified through specific testing methods or validation procedures, ensuring each aspect is properly addressed.

Table 3. Requirements Traceability Matrix – ABIS

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
System Features				
Vehicle Detection, Re-Identification, and Tracking				
1.1.1	The vehicle detection system shall utilize non-intrusive forms of detection that can be easily and flexibly adjusted to changing conditions, such as lane shifts, construction, etc.	Field Infrastructure	Analysis	UN-12, UN-42
1.1.2	The vehicle detection system shall detect both moving and stationary vehicles (i.e., speeds of 0 MPH).	Field Infrastructure	Demonstration	UN-19
1.1.3	The vehicle detection system shall identify which lane a vehicle is traveling in. Some ports of entry may have up to 12 lanes.	Field Infrastructure	Demonstration	UN-12
1.1.4	The vehicle detection system shall classify vehicle types. At a minimum, it shall differentiate between passenger vehicles, buses, and commercial trucks.	Field Infrastructure	Demonstration	UN-17, UN-29
1.1.5	The system shall re-identify vehicles between two fixed points to measure border wait times and travel times.	Field Infrastructure	Demonstration	UN-12
1.1.6	The system shall measure how vehicles divert from one port of entry to another. For example, vehicles traveling northbound on I-5 have the option of diverting from Peace Arch to Pacific Highway at SR 543.	Field Infrastructure	Demonstration	UN-18, UN-23
1.1.7	The system shall automatically identify what type of lane an inspection booth is serving. Lanes dynamically change from open/closed, general/NEXUS, etc.	Field Infrastructure, Device Integration Module	Demonstration	UN-11
1.1.8	The system shall be capable of ingesting external data sources, such as crowdsourced location-based services data, freight data from private trucking companies, etc.	Data Aggregation Engine	Analysis	UN-7, UN-16, UN-17

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
1.1.9	The system shall include a smartphone application for dynamic vehicle tracking to measure border wait times and travel times. See the Requirements Traceability Matrix for the BWT App for details.	Mobile App	Analysis, Demonstration	UN-3, UN-8, UN-12, UN-13, UN-16, UN-17, UN-18, UN-19, UN-20, UN-22, UN-23, UN-25
Border Wait Time and Travel Time Measurement and Prediction				
1.2.1	The system shall provide measurements and predictions of border wait times and travel times for general purpose vehicles, NEXUS vehicles, commercial/FAST vehicles, and buses.	Real-Time Analysis Module	Demonstration	UN-13
1.2.2	The system shall measure border wait times and travel times in real time. Border wait time is defined as the time it takes from a vehicle joining the back-of-queue to when it reaches the inspection booth. Travel time is defined as the time it takes a vehicle to reach the back-of-queue from its current location. In addition, the system shall provide the actual and estimated wait times as a measure of reliability and accuracy.	Real-Time Analysis Module	Demonstration	UN-13
1.2.3	The system shall provide predictions based on real-time measurements and historical data that has been collected by the system, as well as data that has been collected previously by the Cascade Gateway Border Data Warehouse.	Reporting & Analytics Engine	Demonstration	UN-13

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
1.2.4	The system shall convert the measurements and predictions into environmental metrics, including greenhouse gas emissions, fuel consumption, etc.	Reporting & Analytics Engine	Demonstration	UN-14, UN-15
	System Algorithms			
1.3.1	The system shall implement algorithms to filter data noise.	Data Aggregation Engine	Analysis, Demonstration	UN-12
1.3.2	The system shall avoid proprietary software and shall utilize open standards and algorithms.	Data Aggregation Engine	Analysis, Demonstration	UN-6
1.3.3	The system shall aggregate data from various data sources (e.g., field equipment like Bluetooth/Wi-Fi readers and vehicle detection systems, mobile app data, etc.) to improve accuracy.	Data Aggregation Engine	Analysis, Demonstration	UN-10, UN-12
1.3.4	The system shall calibrate the data that it collects based on externally-supplied ground-truth information, such as manual vehicle counts.	Data Collection Service	Analysis, Demonstration	UN-10, UN-12
1.3.5	The system shall use machine learning for improved data processing.	ML Model Training and Deployment	Analysis, Demonstration	UN-10
	User Interface			
1.4.1	The system shall provide users with real-time measurements and predictions.	User Interface Module	Demonstration	UN-12, UN-13 UN-18, UN-37, UN-38
1.4.2	The system shall provide users with historical measurements and predictions via the Cascade Gateway Border Data Warehouse.	Historical Data Viewer	Demonstration	UN-28

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
1.4.3	The system shall provide customizable graphical user interfaces based on the type of user. Users may include CBP, CBSA, WSDOT, BCMOTI, WCOG, and the general public.	Dashboard Customization Module	Demonstration	UN-41
1.4.4	The user interfaces shall be customizable to display data that include but are not limited to:	Dashboard Customization Module	Demonstration	UN-33, UN-34, UN-35, UN-36, UN-41
	Number and types of lanes open at each port of entry (inspection agency only).			
	Border wait time for each lane and lane type at each port of entry.			
	Number of vehicles in the queue in each lane and lane type at each port of entry.			
1.4.5	The system shall provide real-time data visualization features. This may include customizable interactive charts and data trend reports to allow sorting and filtering of data that include but are not limited to:	Data Visualization Module	Demonstration	UN-33, UN-34, UN-35, UN-36, UN-41
	Average wait time by hour, day, week, month, and year.			
	Number of vehicles by hour, day, week, month, and year.			
1.4.6	The system shall support exporting visualizations as images or PDFs.	Export Functionality	Demonstration	UN-18, UN-41
1.4.7	The system shall support customizable data processing rules.	Data Processing Rules Engine	Demonstration	UN-18, UN-41
1.4.8	The system shall provide notifications and alerts via email, SMS, and push notifications.	Notification Service	Demonstration	UN-39

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
1.4.9	The system shall provide escalation procedures based on alert severity.	Alert Categorization System	Demonstration	UN-39
1.4.10	The system shall provide users with configurable automated alerts that include but are not limited to:	Alert Configuration Module	Demonstration	UN-39
	Border wait time increasing by a configurable threshold.			
	Number of vehicles increasing by a configurable threshold.			
	Vehicle speeds increasing by a configurable threshold.			
	Suspected issues/inaccuracy with the data.	Anomaly Detection System		
	Devices faults or malfunctions.	Device Health Monitoring Module		
1.4.11	The system shall provide users with "what-if scenario" analysis, allowing users to alter parameters to predict how border wait times will change. Parameters include but are not limited to:	Reporting & Analytics Engine	Analysis, Demonstration	UN-37, UN-38
	Time, day of week, month, etc.			
	Number and types of lanes open at each port of entry.			
	Historical data usage (e.g., prediction based on typical historical data, special events, etc.)			
1.4.12	The system shall support English, Spanish, and French.	Language Localization Module	Demonstration	UN-20, UN-21, UN-22, UN-23

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
1.4.13	The system shall support mobile and desktop platforms.	Cross-Platform Compatibility	Demonstration	UN-20, UN-21, UN-22, UN-23
	Other			
1.5.1	The system shall ensure low data processing latency.	Data Processing Optimization	Analysis, Demonstration	UN-10
1.5.2	The system shall handle high transactions per minute.	High-Volume Data Handling Module	Analysis, Demonstration	UN-10
1.5.3	The system shall support concurrent multi-user access.	Concurrency Management Module	Demonstration	UN-19
1.5.4	The system shall optimize performance under peak loads.	Performance Optimization Module	Analysis, Demonstration	UN-7
1.5.5	The system shall provide performance monitoring and tuning tools.	Performance Monitoring System	Demonstration	UN-10
1.5.6	The system shall support real-time data updates with minimal downtime.	Real-Time Update System	Demonstration	UN-7, UN-11
1.5.7	The system shall provide efficient query processing for rapid response.	Query Optimization Engine	Analysis, Demonstration	UN-10

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
1.5.8	The system shall perform automated backups every 24 hours.	Backup Management System	Demonstration	UN-10, UN-40
1.5.9	The system shall support horizontal scaling to handle increased loads.	Horizontal Scaling Module	Analysis, Demonstration	UN-8
1.5.10	The system shall implement load balancing to distribute traffic.	Load Balancer	Analysis, Demonstration	UN-7
1.5.11	The system shall allow for remote monitoring and management.	Remote Configuration System	Demonstration	UN-40
1.5.12	The system shall support automated system updates.	Database Update and Integration	Demonstration	UN-7, UN-40
Communications				
2.1	The system shall be compatible with all types of network communications that include but are not limited to:	Communications Service	Analysis, Demonstration	UN-32
	Fiber Optic			
	Point-to-Point Wireless			
	Leased Line			
	Cellular			
Access and Security				
3.1	The solution shall be implemented with a security policy that incorporates industry best practices and agency policies.	Compliance Management Module	Analysis	UN-5

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
3.2	The system shall provide user authentication and role-based access control.	Authentication & RBAC Module	Demonstration	UN-5
3.3	The system shall encrypt data in transit and at rest.	Data Encryption Module	Analysis	UN-5
3.4	The system shall support MFA for users.	Multi-Factor Authentication Module	Demonstration	UN-5
3.5	The system shall maintain audit trails for data access and changes.	Audit Trail Module	Analysis, Demonstration	UN-5
Privacy				
4.1	The system shall comply with General Data Protection Regulations, (GDPR) and data privacy regulations.	Compliance Management Module	Analysis	UN-4, UN-5
4.2	The system shall process and store data securely and in accordance with industry best practices.	Compliance Management Module	Analysis	UN-4, UN-5
4.3	The system shall not process, store, or otherwise use license plate information.	Compliance Management Module	Analysis	UN-4
4.4	The system shall process and store Personally Identifiable Information (PII) in accordance with privacy laws in the U.S. and Canada.	Compliance Management Module	Analysis	UN-4
Data Logging and Storage				
5.1	The system shall log data for each lane and lane type and each port of entry that include but are not limited to:	Device Integration Module, Data	Demonstration	UN-28, UN-29

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
	Vehicle Volume	Aggregation Engine, Historical Data Viewer		
	Vehicle Speed			
	Vehicle Classification			
	Detector Occupancy			
	Travel Time			
	Border Wait Time			
	Queue Length/Back-of-Queue Location			
5.2	The system shall log all alerts, failures, and malfunctions.	Device Health Monitoring Module, Reporting & Analytics Engine, Historical Data Viewer	Demonstration	UN-39
5.3	The system shall provide customizable reports.	Reporting & Analytics Engine, Historical Data Viewer	Demonstration	UN-41
5.4	The system shall support batch processing for historical analysis.	Batch Processing Engine, Reporting & Analytics Engine, Historical Data Viewer	Demonstration	UN-41

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
5.5	The system shall archive all data to the Cascade Gateway Border Data Warehouse indefinitely.	Reporting & Analytics Engine, Historical Data Viewer	Demonstration	UN-27
5.6	The system shall archive all raw data in a format that is compatible with the existing Cascade Gateway Border Data Warehouse.	Reporting & Analytics Engine, Historical Data Viewer	Analysis, Demonstration	UN-30, UN-31
5.7	The system shall provide interfaces to allow data collected from the system to be exported or integrated to third party websites, tools, etc.	Data Interfaces	Analysis	UN-26
Failure Events and Fallback				
6.1	The system shall incorporate health checks for system components.	System Health Check Module	Analysis, Demonstration	UN-10
6.2	The system shall operate with 99.9% uptime.	System Integration	Analysis	UN-10, UN-32
6.3	The system shall provide data redundancy, allowing for continued system operation in the event of device and/or communications failures.	Data Redundancy & Backup System	Analysis, Demonstration	UN-10
6.4	In the event of a device failure, the system shall automatically switch to an alternative data source and issue an alert to users.	Data Redundancy & Backup System	Analysis, Demonstration	UN-10
6.5	In the event of a communications failure, the system shall automatically switch to historical data and issue an alert to users.	Data Redundancy & Backup System	Analysis, Demonstration	UN-10
Existing Systems and Infrastructure				

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
7.1	The system shall be compatible with mounting on standard WSDOT and BCMOTI poles and infrastructure.	Field Infrastructure	Analysis, Inspection	UN-19
7.2	The system shall be compatible with existing WSDOT and BCMOTI cabinets	Field Infrastructure	Analysis, Inspection	UN-19
7.3	The system shall interface, in real time, with existing WSDOT and BCMOTI traveler information systems to automatically provide border wait times, travel times, and alerts.	Data Interfaces	Analysis, Demonstration	UN-20, UN-21, UN-22, UN-23, UN-24, UN-25, UN-26
7.4	The system shall automatically disseminate border wait times and travel times based on the location of the existing ITS field device (e.g., DMS/VMS and HAR). This information shall include the predicted border wait times and travel times at the time of the vehicle's arrival at the back-of-queue.	Data Interfaces	Analysis, Demonstration	UN-20, UN-21, UN-22, UN-23, UN-24, UN-25, UN-26
7.5	The system shall automatically disseminate alerts to drivers in the event of increasing border wait times and travel times and provide a suggested diversion to an alternative port of entry.	Data Interfaces	Analysis, Demonstration	UN-20, UN-21, UN-22, UN-23, UN-24, UN-25, UN-26
Durability				

Requirement ID	Requirement Description	Module/ Functionality	Verification Method	User Need ID Reference
8.1	The hardware of the solution shall be designed for use in an outdoor environment.	Field Infrastructure	Analysis, Inspection	UN-10, UN-19
8.2	The hardware of the solution shall be designed to resist normal “wear and tear” damage from day-to-day use.	Field Infrastructure	Analysis, Inspection	UN-10, UN-19
8.3	The hardware of the solution shall be designed to withstand temperatures ranging from 0°F – 140°F.	Field Infrastructure	Analysis, Inspection	UN-10, UN-19

Requirements Traceability Matrix for the BWT App

The requirements traceability matrix for the BWT App, shown in Table 4, links the **requirements** to the **app modules**, ensuring that key functionalities (user interaction, GPS tracking, trip monitoring, and data collection) are mapped and implemented to meet the overall system goals of providing accurate BWT and improving user experience.

Requirements are classified based on the following categories:

- Requirement ID (FR): Each functional requirement is numbered (FR 1, FR 2, etc.) and briefly described.
- Requirement Description: This column details what the system or app must fulfill, such as user registration, GPS tracking, real-time updates, or data collection for prediction models.
- Related Modules: Lists the relevant app modules responsible for meeting the corresponding requirement. Modules like "Registration," "Track Trip," and "Messaging" are tied to specific functionalities in the app as described in section 3.2 of this document.
- Notes: Provides additional clarification on how a particular module contributes to fulfilling the requirement.

Table 4. Requirements Traceability Matrix – BWT App

Requirement ID	Requirement Description	Related Modules	Verification Notes
FR 1	The app should allow users to create an account and store their information.	2.4.1 Registration	The registration module is directly responsible for fulfilling this requirement.
FR 2	Users should be able to configure their preferences, including allowing/disallowing GPS tracking.	2.4.2 Settings	Settings allow GPS preferences configuration, crucial for tracking in the border queue.
FR 3	Users should be able to select their vehicle type and desired POE (Point of Entry).	2.4.3 POE Selection	Collects vehicle and POE selection data, as well as GPS information for better BWT prediction.
FR 4	The app should collect GPS information from users while they are in the border queue to improve wait time predictions.	2.4.2 Settings 2.4.3 POE Selection 2.4.4 Start Trip 2.4.5 Track Trip	GPS tracking is enabled through settings, and location data is continuously collected during POE selection, trip initiation, and while tracking the trip.
FR 5	Users should be able to receive real-time updates about their trip and border wait times, using GPS data.	2.4.4 Start Trip 2.4.5 Track Trip	Start Trip and Track Trip modules rely on GPS data for real-time updates and trip monitoring.
FR 6	The app should retrieve and display the current border wait times and	2.4.3 POE Selection 2.4.4 Start Trip 2.4.5 Track Trip	Wait times and POE statuses are fetched from the BWT and POE Information

Requirement ID	Requirement Description	Related Modules	Verification Notes
	status based on the user's selected POE and GPS location.		services based on GPS and POE selections.
FR 7	Users should be able to receive alerts and notifications during their trip.	2.4.6 Messaging	Messaging module provides notifications based on BWT and trip status.
FR 8	The app should allow users to plan a trip, including selecting a POE, lane type, and intended crossing time, and receive predicted border wait times based on historic data and predictive AI models.	2.4.7 Plan Trip	Plan Trip module leverages historic wait times and AI models to predict future border wait times, enhancing the user experience with better planning.
FR 9	The app should continuously track the user's trip, including GPS location, to provide real-time updates and adjust trip predictions based on current traffic and border conditions.	2.4.5 Track Trip	Continuous tracking of user location and traffic updates via GPS improves predictions and provides real-time updates during the trip.
FR 10	The system should allow users to ask questions about border crossing procedures and receive real-time responses from the AI Assistant.	2.4.8 AI Assistant	AI Assistant module answers user inquiries, enhancing the experience with real-time assistance based on the BWT system.
FR 11	The app should store trip details and preferences for future reference and planning.	2.4.2 Settings 2.4.3 POE Selection 2.4.4 Start Trip 2.4.7 Plan Trip 2.4.5 Track Trip	User preferences, trip details, and trip history are stored for future use across multiple modules.
FR 12	The system should store and analyze GPS data from users in the border queue to improve future wait time predictions through machine learning models.	2.4.5 Track Trip 2.4.7 Plan Trip	GPS data is collected and stored during tracking, contributing to AI models used for future BWT predictions.
FR 13	The app should allow for dynamic updates based on real-time traffic, POE status, and border wait time information from external APIs (Map API, Traffic Information API).	2.4.5 Track Trip 2.4.4 Start Trip 2.4.7 Plan Trip	Real-time updates from external APIs are integrated into the tracking and planning modules for better predictions and adjustments.
FR 14	The system should communicate trip details and any relevant changes to the user in real-time.	2.4.5 Track Trip 2.4.6 Messaging	Trip updates, including any changes based on traffic or border conditions, are communicated to users in real-time via notifications

Requirement ID	Requirement Description	Related Modules	Verification Notes
			and updates during tracking.
FR 15	The app should provide real-time POE and lane status based on user's selection and GPS data.	2.4.3 POE Selection 2.4.4 Start Trip 2.4.5 Track Trip	POE and lane information are displayed to the user based on the selected POE and real-time data.
FR 16	The system should store user preferences and trip details in a secure manner, ensuring data privacy and integrity.	2.4.1 Registration 2.4.2 Settings 2.4.7 Plan Trip	Security requirements are met by storing user data securely through Account and Trip services.
FR 17	The app should update the central system with trip and GPS data to provide accurate wait time predictions for all users based on the aggregated data.	2.4.5 Track Trip 2.4.7 Plan Trip 2.4.8 AI Assistant	Aggregated trip data and GPS information help refine wait time predictions, and AI Assistant improves answers based on this data.

5. IMPLEMENTATION APPROACH

This section summarizes the overall implementation approach for this project, which will be deployed under Stage 2 of the SMART Grants Program. Additional details can be found in the Implementation Report.

5.1. Implementation Timeline

The following figure provides a task-based timeline for the ABIS project.

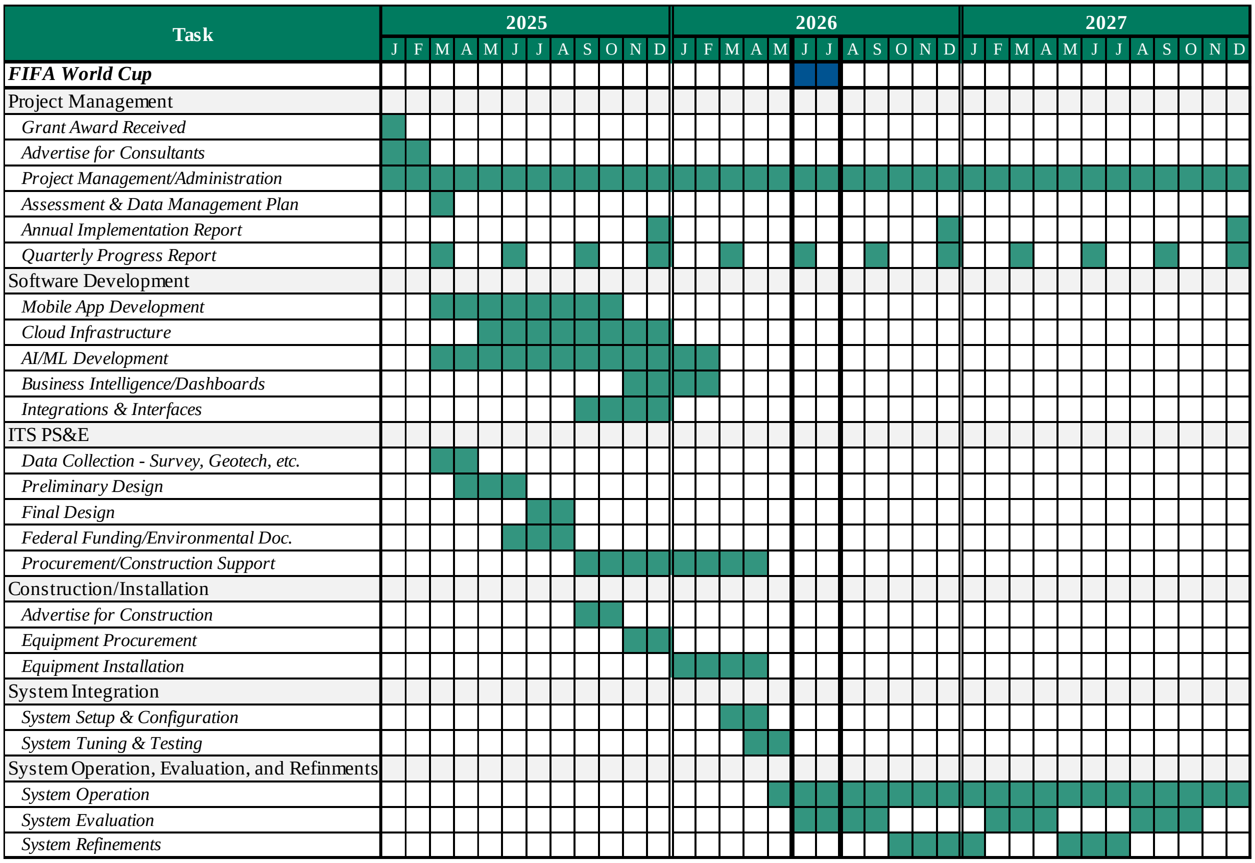


Figure 23. Implementation Timeline

5.2. Implementation Cost Estimate

The total estimated cost of the project, including design, implementation, and operations and maintenance (for two years) of the radar detection system, Bluetooth/Wi-Fi reader system, the BWT app, and the back-end systems is $8,412,400 (USD). This total cost includes costs associated with the procurement and installation of equipment on the Canadian side as well. However, only funds for the U.S. deployment ($6,599,400 [USD]) are currently funded through the Stage 2 SMART grants program; funding is concurrently being sought on the Canadian side with Canadian partners including BCMOTI and Transport Canada. The figure below provides a summary of the implementation cost estimate for the U.S. deployment.

SF-424A & SF-424C Budget Categories										
Task	Personnel	Travel	Contract.	Construction						Total
				A&E	Other A&E	Inspect.	Construct.	Equipment	Misc.	
Project Management	$ 550,000	$ 18,300								*$ 568,300*
Software Development		$ 4,700	$ 2,015,000							*$ 2,019,700*
ITS PS&E	$ 38,000	$ 1,700		$ 647,000	$ 50,000					*$ 736,700*
Construction/Installation	$ 72,000	$ 1,700				$ 54,000	$ 863,000	$ 551,000	$ 20,000	*$ 1,561,700*
System Integration		$ 4,700	$ 668,000							*$ 672,700*
System Op., Eval. & Refinements		$ 6,300	$ 1,034,000							*$ 1,040,300*
Total	*$ 660,000*	*$ 37,400*	*$ 3,717,000*	*$ 647,000*	*$ 50,000*	*$ 54,000*	*$ 863,000*	*$ 551,000*	*$ 20,000*	$ 6,599,400
				$ 2,185,000						

Figure 24. Implementation Cost Estimate (U.S. Only)

5.3. Major Project Tasks

The following major tasks are envisioned for the project. Additional and more detailed tasks with work breakdown structure can be added during the detailed project design.

<u>Task 0: Project Management</u>

- **Advertisement for Consultants**. One of the first tasks will be developing a Request for Qualifications for consultant services to assist with the management, design, development, facilitation, and implementation of the Stage 2 project.
- **Grant Requirements**. This includes completing the Assessment Plan, Data Management Plan, Annual Implementation Report, and Quarterly Progress Reports. This also includes travel for three trips to Washington, DC/Cambridge, MA for four staff members, as defined in the NOFO.
- **Project Management**. This includes overall project management and administration tasks, including the development of a Project Management Plan, which will be developed at the onset of the project, consistent with the Project Management Institute's Project Management Body of Knowledge guidance.

<u>Task 1: Detailed Design</u>

The first task of the project in Stage 2 is the comprehensive build-quality detailed design of the various system components which include system hardware, software including the BWT app, and the communications system per applicable, local, state, and federal standards.

<u>Task 1.1: ITS Plans, Specifications, and Estimates (PS&E)</u>

- **Data Collection**. This is anticipated to include collection of geotechnical data for designing pole foundations (should new poles be needed) and aerial imagery (given the condensed project schedule due to the need to meet the 2026 FIFA World Cup, the use of aerial imagery is proposed for the development of the ITS PS&E over full topographic survey information), if needed.

- **PS&E Development**. This includes the design of the physical infrastructure (e.g., radar detection and Bluetooth/Wi-Fi readers), along with any supporting infrastructure (e.g., poles, foundations, cabinets, power, and communications systems) that may be needed. Federal funding documentation, including NEPA environmental documentation/checklists, proprietary items certification, and public interest findings will also be prepared during this time. As a state agency regularly involved with construction projects, WSDOT is very familiar with these requirements.
- **Procurement/Construction Support**. This includes consultant support during the procurement, as well as support during construction of the physical infrastructure.

Task 1.2: Software Development

The software development effort should be executed systematically, adhering to a structured Software Development Life Cycle (SDLC) to ensure quality, efficiency, and alignment with stakeholder needs. The process should begin with comprehensive planning to gather requirements from project stakeholders, followed by designing the system architecture and user interfaces tailored to the solution's goals. Implementation should focus on delivering each component, including sensor integrations, predictive models, and the mobile app, in a modular and iterative manner. Rigorous testing is essential to validate the functionality and accuracy of the solution, especially the prediction models and real-time data integrations. Deployment must be handled carefully to ensure smooth operation across cloud infrastructure, mobile platforms, and connected systems. Finally, continuous maintenance and updates will ensure the solution remains reliable and effective. Each of these phases will be detailed further in the subsequent description of the SDLC, illustrating how a disciplined approach drives successful software delivery.

- **Mobile App Development**. This includes developing the software architecture, specifications, user interface, and iOS/Android apps, including associated testing and documentation.
- **Cloud Infrastructure**. This includes developing and setting up the cloud infrastructure that is needed to support the ABIS.
- **AI/ML Development**. This includes developing the AI and ML software models that will enable the predictive analytics capabilities of the ABIS.
- **Business Intelligence/Dashboards**. This includes developing custom dashboards for the agencies, as well as providing a user-friendly interface for accessing the predictive analytics.
- **Integrations & Interfaces**. This includes developing integrations and interfaces with existing and future systems like the CGBDW, DMS/VMS, HAR, and travel information websites.
- **Acceptance Testing.** This ensures that the solution meets all specified requirements and functions correctly in real-world scenarios, validating its readiness for deployment.
- **Documentation.** This provides comprehensive records of the system's architecture, functionality, and usage guidelines, ensuring clarity for stakeholders, developers, and end-users throughout the software lifecycle.

The Software Development Life Cycle (SDLC), as shown in Figure 25, is a structured process that guides the development of software applications through distinct phases, ensuring systematic progression from conception to deployment and maintenance. The SDLC includes the following stages:

1. **Planning**: This initial phase involves gathering and analyzing requirements to understand the project's scope and objectives. For the software components – Mobile App Development, Cloud Infrastructure, AI/ML Development, Business Intelligence/Dashboards, and Integrations & Interfaces – this step would entail detailed discussions with stakeholders to capture functional and technical requirements.
2. **System Design**: Based on the gathered requirements, this phase focuses on creating detailed design specifications. This includes defining the software architecture, selecting appropriate technologies, designing user interfaces, and planning integrations with existing systems like CGBDW, DMS/VMS, HAR, and travel information websites.
3. **Implementation (Coding)**: In this stage, developers write the actual code for the software components. For Mobile App Development, this means developing applications for iOS and Android platforms. For Cloud Infrastructure, it involves setting up the necessary cloud services. AI/ML Development would focus on building predictive analytics models, while Business Intelligence/Dashboards would involve creating user-friendly dashboards for agencies.
4. **Integration and Testing**: After coding, the software components are integrated and rigorously tested to identify and resolve defects. This includes unit testing, system testing, and acceptance testing to ensure each component functions correctly and meets the specified requirements.
5. **Deployment**: Once testing is complete, the software is deployed to the production environment. This involves installing the software on user devices, configuring cloud infrastructure, and ensuring all integrations are operational.
6. **Maintenance**: Post-deployment, the software enters the maintenance phase, where it is monitored for performance, and any issues are addressed. This includes updating documentation, providing user support, and implementing enhancements as needed.

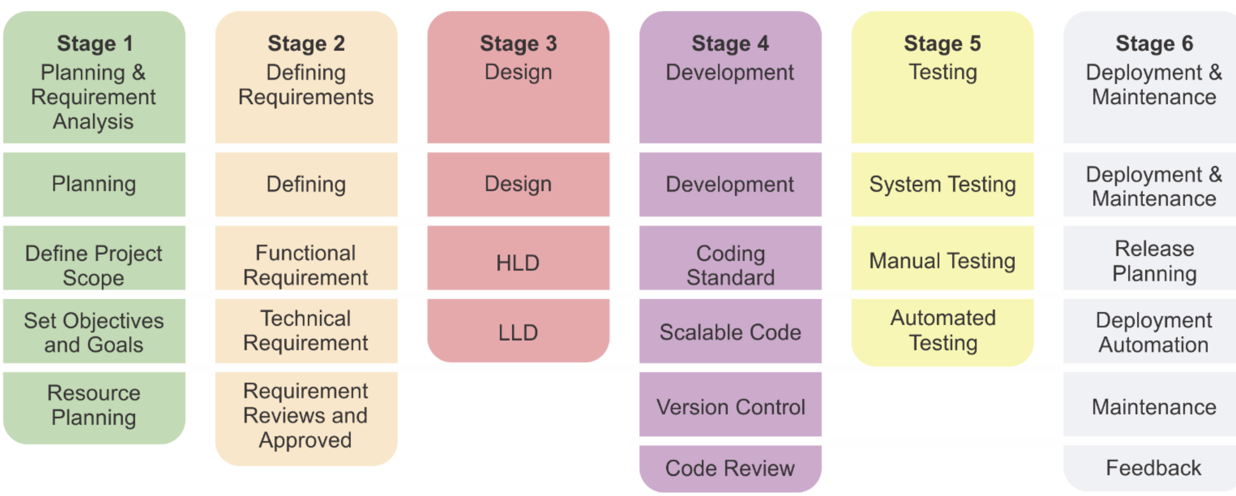


Figure 25. Six Stages of the Software Development Lifecycle

<u>Task 2: Construction/Installation</u>

- **Advertise for Construction**. This involves advertising the construction documents developed as part of the ITS PS&E for contractors to furnish and install the equipment.
- **Equipment Procurement**. During this time, equipment will be procured by the contractor. Given that the physical equipment will be commercial off-the-shelf products, procurement lead times are not expected to be too lengthy.

- **Equipment Installation**. During this time, the contractor will be constructing the physical improvements and installing the equipment. Equipment is generally expected to use existing infrastructure (e.g., cabinets, power, communications, poles, etc.) and will have minimal impacts on moving traffic.

Task 3: System Integration

- **System Setup and Configuration**. Once the equipment and the ABIS software systems have been installed and tested, the system can be configured to ensure that the roadside equipment, the mobile app, and the back-end systems are functioning cohesively.
- **System Tuning and Testing**. This task will involve an operational test (e.g., 30-days), during which the system will be tested for bugs and defects. The system's parameters will be tuned and tweaked to ensure the data is timely, accurate, and meets expectations. There are several new testing techniques and processes that have evolved to ensure efficiency. This includes Continuous Test-Driven Development (CTDD). Unlike traditional testing where software is tested at the end of development, continuous testing is done in multiple stages of software and its module development for instant feedback.

Task 4: System Operation, Evaluation, and Refinement

- **System Operation**. The project aims to be operational in advance of the first match of the FIFA World Cup in June 2026, meaning it will have been tested, configured, and tuned to ensure proper operation. This task includes staff time, warranty, support, and hosting fees needed to operate the system for the duration of the project. During the FIFA World Cup, the system's performance will be monitored and evaluated – see below.
- **System Evaluation**. Given the tight timeframe associated with this project, it is anticipated that the system will undergo a series of evaluations to determine if the system fully meets the needs of its stakeholders. After the FIFA World Cup concludes, two separate stages of system evaluation will be conducted to identify any deficiencies, necessary improvements, and/or additional features desired.
- **System Refinement**. Based on the System Evaluation, the system may undergo additional refinement. After the first stage of evaluations, refinements will be implemented. The system will then undergo a second stage of evaluations, providing a final opportunity for additional refinements to the system to be made. After this final stage of refinements, a final project evaluation will be conducted to validate that the project meets the needs, requirements, and objectives of the project.