Real-Time Edge Collaborative Traffic Signal Control System Solution

Version: 1.0

TraffiClair Technology Co., Ltd.

Version Log

Date	Version	Description
2025.1.2	V1.0	Created.

Content

1. Solution Overview 5
1.1 Background Introduction 5
1.2 Significance of the Construction 6
2. Introduction to the Edge Collaborative Signal Control System** 9
2.1 System Advantages 9
2.2 System Architecture 10
2.3 Key Technologies 12
2.4 System Composition 15
2.4.1 Phased Array Radar - Real-Time Monitoring of Traffic Flow 15
2.4.2 Edge Computing Control Unit - Precise Control of Traffic Signals 17
2.4.3 Comprehensive Traffic Signal Control Algorithm 18
2.4.4 Comprehensive Traffic Signal Optimization Control Platform 19
2.5 Platform Detailed Introduction 20
2.5.1 Real-time Traffic Situation Monitoring The platform can monitor real-time traffic conditions for roads by region, trunk roads, and intersections. 20
2.5.2 Traffic Data Prediction 25
2.5.3 Traffic Situation Playback 26
2.5.4 Full-Angle Intersection Simulation 27
2.5.5 Historical Data Query and Display 28
2.5.6 Traffic Data Comparative Analysis 31
2.5.7 Traffic Abnormal Event Monitoring 33
2.5.8 Device Management Functionality 34
2.5.9 Device Monitoring and Maintenance 35
2.5.10 Road Network Configuration and Management 35
2.5.11 System Configuration and Management 37
2.6 System Application Features 39

2.6.1 Single-Point Intelligent Control....39
2.6.2 Reverse Overflow Control....40
2.6.3 Mainline Coordination Control....41
2.6.4 Regional Coordination Control....42
3. Equipment Requirements....44
3.1 Front-end Intersections....44
3.2 Command Center....44

1. Solution Overview

1.1 Background Introduction

Transportation, as the foundation of urban development, serves as the first window showcasing a city's image and reflects its governance level. Comprehensive transportation infrastructure and equipment are critical in supporting and ensuring a city's ability to achieve new economic growth under evolving conditions. However, in many cities, there remains a significant gap between the current level of traffic management infrastructure and the requirements for intelligent traffic management.

The **"Outline for Building a Strong Transportation Nation"** emphasizes the need to vigorously develop intelligent transportation, promoting the deep integration of new technologies—such as big data, the Internet, artificial intelligence, blockchain, and supercomputing—into the transportation industry. It aims to construct an advanced and ubiquitous transportation information infrastructure. Similarly, the **"14th Five-Year Plan for Digital Transportation Development"** outlines the necessity of accelerating transportation-related new infrastructure, integrating emerging technologies with traditional transportation infrastructure, enabling the digital transformation and intelligent upgrading of these systems, and enhancing safety, operational efficiency, and management capabilities. Traffic signal control systems, as one of the most crucial components of intelligent transportation, are fundamental systems that ensure intersection traffic safety. However, most cities still operate fixed-cycle signal timing systems with limited efficiency and a low degree of intelligence. The **"Real-Time Edge Collaborative Traffic Signal Control System"** by TraffiClair is an artificial intelligence-based optimization system for real-time traffic big data. It leverages proprietary traffic signal control radar and edge computing control units to detect real-time traffic flow information and dynamically adjust signal durations based on traffic volume. This approach enables demand-based vehicle passage, introducing AI-based signal timing that effectively alleviates congestion and improves road traffic efficiency.

This system surpasses the control performance of traditional signal control systems and overcomes the technical limitations of conventional adaptive traffic signal control systems. With exceptional traffic adaptability, it handles various traffic conditions, including sparse traffic, saturated/oversaturated flow, and random traffic. By implementing real-time adjustments at single intersections, the system enables dynamic and integrated control across corridors and regions, establishing itself as the next generation of intelligent traffic signal control systems. Its effectiveness has been recognized by traffic police departments across multiple regions. The system builds multidimensional monitoring and precise management capabilities, enhancing the intelligence of traffic signal management and advancing smart transportation development.

Taking a specific city project as an example, 142 intersections have adopted this system, resulting in a **15%–30% improvement in road traffic efficiency**. At peak intersections, vehicle queue lengths have been reduced from 50–100 meters to less than 50 meters, achieving a **50% or more reduction**. On average, each individual saves **60.8 hours of travel time per year**. With approximately 300,000 vehicles traveling daily within the city, each vehicle saves **5 minutes of idling per day**, with an average idling fuel consumption of 1.6 liters per hour. This equates to a daily fuel savings of **40,000 liters citywide** and an annual fuel savings of **14.6 million liters**.

1.2 Significance of the Construction

Building an "intelligent" and "refined" comprehensive traffic signal control system will significantly contribute to urban development.

1. **Enhancing the intelligence and informatization of traffic signal control systems**

   This system integrates real-time traffic flow monitoring, automated and intelligent management, and big data platform visualization. It represents a leap forward from the existing "experience-based" signal control systems to "intelligent" systems, providing a world-class traffic signal management solution for traffic management

authorities.

2. **Reducing driver waiting time and improving driving experience**

   By dynamically adjusting regional control strategies in real time based on road network characteristics and traffic flow, the system employs various methods, such as coordinated green waves for corridors, crossing green waves, and single-intersection adaptive control. These approaches minimize vehicle stops at intersections and reduce red-light waiting times, significantly improving the driving experience and shortening travel durations.

3. **Supporting smart city development with cutting-edge technology**

   Leveraging our proprietary phased-array radar, the system conducts wide-area, real-time monitoring of traffic conditions. This radar has consistently ranked first in both domestic and international comparative tests, receiving widespread recognition for its technological advancement. By integrating radar monitoring data with the signal control system, this system achieves a seamless fusion of monitoring and intelligent control, marking a pioneering achievement in the industry. Its exceptional adaptability allows it to handle sparse, saturated, or random traffic, effectively accommodating the surging traffic volumes associated with urban development.

4. **Improving intersection efficiency and mitigating peak-hour congestion**

   The system's real-time road condition monitoring and dynamic signal timing adjustment significantly enhance traffic flow. By reducing delays caused by traditional intersection signal timing, it not only improves vehicle passage speeds but also boosts overall road network efficiency.

5. **Providing 24/7 intelligent traffic command comparable to an experienced officer**

   The system functions like having a highly skilled traffic officer at every intersection 24/7. It greatly reduces the operational pressure on traffic police departments by enabling intelligent, human-centered traffic management. This reduces the workload of on-site traffic control while increasing intersection efficiency, freeing up human resources for

other traffic management tasks.

6. **Laying the foundation for and leading smart traffic management initiatives**

   By implementing a phased-array radar-based real-time signal optimization system, the system achieves highly intelligent traffic management. It enhances urban traffic management capabilities, optimizes road resource utilization, increases vehicle throughput and traffic efficiency, and reduces congestion-related environmental pollution, thus contributing to energy conservation and emission reduction.

7. **Improving citizen satisfaction and reducing unnecessary waiting times**

   The system minimizes unnecessary red-light waiting and vehicle stops, directly improving the "happiness index" of traffic participants. Unlike traditional systems that cannot adapt signal timing to real-time traffic changes, this system prevents the frustration caused by "empty signals" and wasted time. By reducing unnecessary waiting and stops, it enhances the overall experience of urban commuting.

2. Introduction to the Edge Collaborative Signal Control System**

The "Real-Time Edge Collaborative Traffic Signal Control System" builds upon existing traffic signal control infrastructure, leveraging AI deep learning algorithms to enhance individual intersections. This system empowers traffic signal control systems with intelligent capabilities, achieving smarter and more efficient control of traffic flow.

2.1 System Advantages

Once implemented, the **"Real-Time Edge Collaborative Traffic Signal Control System"** will enable real-time intelligent regulation of traffic signals at urban road intersections and dynamic, comprehensive traffic flow monitoring. The system boasts the following advantages:

1. **Comprehensive Dynamic Monitoring of Traffic Flow**

   The system operates reliably under all weather conditions, unaffected by adverse environments, to deliver accurate and stable monitoring of road traffic flow. It monitors, records, and analyzes a variety of road traffic data continuously.

2. **Real-Time Intelligent Adjustment of Intersection Signals**

   Traffic signal timing is dynamically adjusted in real time based on road traffic flow and congestion levels, ensuring optimal control of vehicle movement.

3. **Automated Line and Regional Control**

   The system monitors traffic flow and conditions on specific roadways and in broader regions in real time, adjusting control strategies automatically based on the traffic situation. These strategies include dynamic green wave coordination, maximum flow saturation control, queue retention during oversaturation, and emergency control for

oversaturation conditions.

4. **Timely Response to Emergencies**

   In cases of traffic emergencies such as reverse overflow, intersection "gridlock," or abnormal congestion, the system promptly detects and resolves the issue automatically, preventing further blockage and ensuring smooth traffic flow.

5. **Rapid Detection and Localization of Traffic Anomalies**

   The phased-array radar can track vehicle trajectories, enabling automatic detection of issues like reverse overflow, excessive queue lengths, and severe congestion. These events are immediately reported to the central platform for resolution.

6. **Multi-Dimensional Data Visualization**

   Leveraging the wide-area monitoring capabilities of phased-array radar, the system provides diverse and multi-dimensional traffic data. These include sectional traffic flow, average vehicle speed, headway, vehicle spacing, queue length, and more. This rich dataset supports traffic management authorities in making more precise and effective decisions.

7. **Long Service Life and Low Maintenance**

   The use of radar as the core road condition sensor ensures a longer service life compared to inductive loops or cameras. Radar sensors are less susceptible to damage during road construction, require lower maintenance costs, and provide long-term reliable data to support traffic optimization initiatives.

2.2 System Architecture

The system is structured in three hierarchical layers from bottom to top: **Front-End Perception Layer**, **Edge Computing Layer**, and **Central Command Layer**.

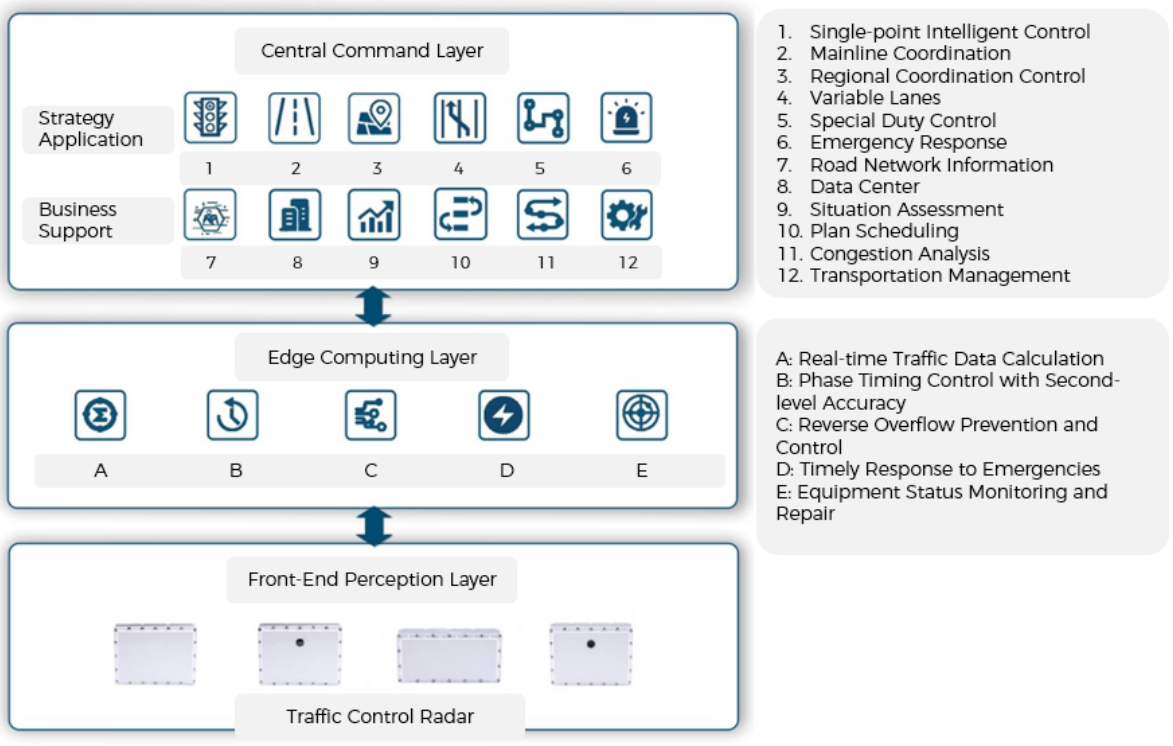


Figure 2.1: System Architecture

Front-End Perception Layer: This layer mainly consists of phased array radars and other perception monitoring equipment to monitor vehicles at intersections and collect traffic data. It provides 24/7, all-round real-time monitoring of traffic flow and incidents. The collected data includes traffic volume, average speed, vehicle type, queue length, occupancy rate, headway time, and more.

Edge Computing Layer: Based on real-time traffic flow data, this layer performs intelligent control of intersections in seconds. It prevents and controls events such as reverse overflow and responds to emergencies. It also processes and applies the collected traffic data and monitors the operating status of radar and other equipment for maintenance and management.

Central Command Layer: This layer supports business functions such as road network information viewing and management, data statistics and applications, traffic situation

assessment, solution scheduling and application, congestion analysis and handling, and equipment operation and maintenance management. It also provides upper-level traffic control applications, including single-point intelligent control, trunk coordination, regional coordination, smart variable lanes, special service control, and event response.

2.3 Key Technologies

(1) **Phased Array Radar Acquisition Technology**

The system frontend uses the most advanced phased array smart sensing millimeter-wave radar (hereafter referred to as phased array radar), a typical high-tech achievement resulting from military-civilian integration technology transfer. In the military, phased array technology is widely used in advanced equipment such as aircraft, ships, and missiles. It features multi-target detection, versatile functionality, strong mobility, fast response speed, high accuracy, strong anti-jamming ability, and high reliability.

The phased array radar, after being adapted for civilian use, is currently the world's top millimeter-wave radar. As a non-invasive traffic information collection sensor, it can be easily installed at intersections to detect multiple lanes, multiple targets, and provide high accuracy. It collects real-time, comprehensive, and precise traffic data at intersections, including real-time location, instant speed, vehicle type classification, lane information, traffic volume, average speed, time occupancy rate, headway time, queue length statistics, and regional traffic flow statistics.

This phased array radar is a 100% independently developed traffic flow sensing product by our company. It is the most advanced millimeter-wave radar detector currently on the market, meeting the relevant safety frequency policies and regulations set by the Ministry of Industry and Information Technology and the Ministry of Transport. From the source, it prevents any frequency interference that may affect future vehicle-road coordination systems, autonomous driving, and other systems.

(2) Real-Time Control Technology

Data collected by the frontend phased array radar is transmitted in real-time over the network to the edge computing center and command center. The edge computing unit utilizes artificial intelligence engines to determine the optimal signal timing, which is executed in real-time by the traffic signal controllers, allowing for dynamic signal control at intersections. Simultaneously, the data is synchronized back to the command center to enable coordination control of trunk roads and regions.

The command center integrates functions such as traffic situation monitoring, automatic traffic signal control, emergency response decision-making, and equipment maintenance. Using computer-based artificial intelligence traffic simulation models, a digital twin of the road network is created, allowing operators to view the city's road traffic operations from a "bird's-eye view" and adjust it in real-time. It also monitors intersection and regional traffic status information, including traffic saturation, congestion index, average speed, and vehicle count. In the event of a sudden traffic incident, the system will trigger an emergency response decision mechanism and scientifically adjust the relevant area's traffic signal release based on the on-site traffic situation.

This system deploys high-precision, multi-target sensing and millisecond-level response equipment at the frontend, using edge computing control technology to automatically direct traffic signals based on real-time traffic volume with millisecond-level response time. This avoids the traditional "data transmission → central computation → timing issuance" model, which causes delays and system instability. It represents a leap in intelligent traffic technology from the "past" to the "present," revolutionizing the current common "traffic brain" control technologies.

For example, at a certain intersection, the traffic volume throughout the day is shown in **Figure 2-2**, the original fixed signal timing is shown in **Figure 2-3**, and the real-time adjusted signal timing after optimization by the system is shown in **Figure 2-4**. The signal timing can be adjusted in real-time based on traffic volume, with the signal cycle time highly matched to the traffic flow.

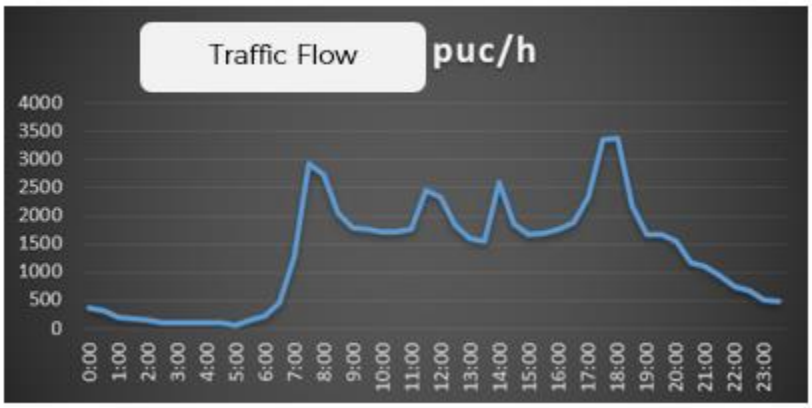


Figure 2.2: Traffic volume throughout the day

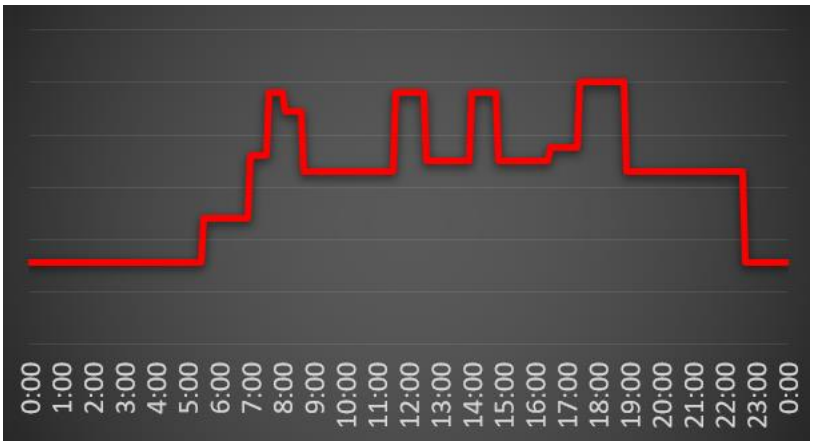


Figure 2.3: Fixed signal timing

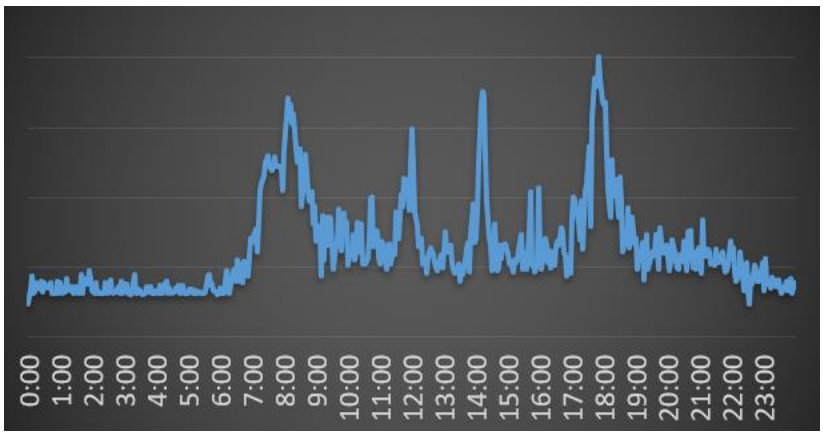


Figure 2.4: The signal timing generated by the intelligent system

2.4 System Composition

2.4.1 Phased Array Radar - Real-Time Monitoring of Traffic Flow

Our company uses high-performance radar sensors as the core means of road traffic perception. This device offers holographic traffic data collection capabilities:

1. **Real-time Vehicle Positioning, Speed Measurement, and Tracking**: It can monitor vehicles within a 400-meter range across 12 lanes, providing real-time location, speed, and tracking information for each vehicle.
2. **Queue Length Statistics**: It can calculate the queue length for each lane within the detection range, offering insights into congestion and traffic buildup.
3. **Average Speed per Lane**: The system tracks the average speed of vehicles on each lane, helping to assess the traffic flow and identify areas with slow-moving traffic.
4. **Multi-dimensional Traffic Flow Data Output**: It outputs a variety of traffic flow data, including vehicle count, lane usage, speed statistics, and other relevant information to assist with intelligent traffic management.
5. **Wide-area Real-time Road Monitoring**: The radar system provides extensive, real-time monitoring of road conditions, covering large areas and ensuring up-to-date traffic data for decision-making.

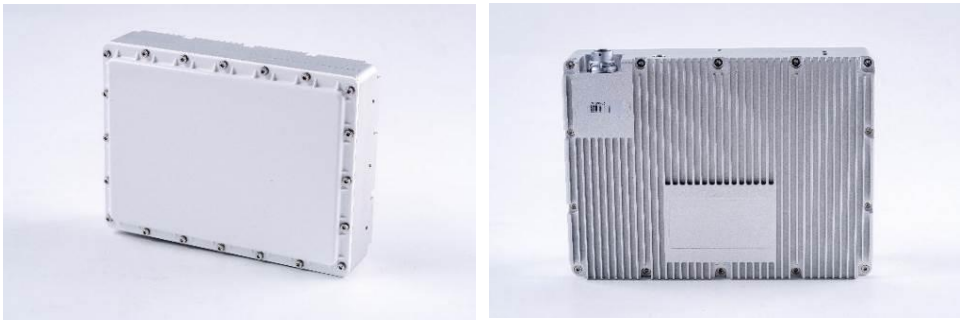


Figure 2.5: Radar image

The radar installation method and coverage area are shown in the following diagram:


Radar 2
Radar 1
Radar 3
Radar 4
Radar 1 coverage

Figure 2.6: Radar Installation Method and Coverage Area

2.4.2 Edge Computing Control Unit - Precise Control of Traffic Signals

As the intelligent control node of the signal control system, the edge computing control unit receives data from multiple radar sensors at the intersection. It processes this data in milliseconds based on a traffic signal comprehensive control algorithm model and then applies real-time control to the traffic signal, dynamically adjusting phase timing to improve intersection efficiency and reduce congestion. The main features and functions are as follows:

1. **Receives Radar Data**: It processes the radar data in milliseconds based on the algorithm model, providing multidimensional parameters for real-time control.
2. **Real-time Generation of Control Plans**: It generates control plans that match traffic volume demands, dynamically adjusting phase timing to achieve precise second-level control without delay.
3. **Monitoring Vehicle Operation**: It monitors the internal and exit vehicle flow at the intersection, intelligently addressing any congestion issues in real-time.
4. **Coordinated Control Between Multiple Intersections**: Through coordination among multiple edge computing control units at different intersections, dynamic coordinated control of traffic flow across routes can be achieved.
5. **Real-time Monitoring of Signal System Communication and Operation**: It monitors the communication and operation of the traffic signal system in real-time, including the status of signal phases and the operating condition of radar and other equipment.

The **ECCU edge computing control unit** is shown in **Figure 2-7**. This unit can interface with most domestic and international traffic signal controllers, allowing for convenient dynamic adjustment of traffic signal timing.



Figure 2.7: Edge Computing Control Unit

2.4.3 Comprehensive Traffic Signal Control Algorithm

Through real-time traffic flow information collected by the phased array radar and the application of AI artificial intelligence technology, the system achieves integrated optimization and control, ranging from intelligent sensing at individual intersections, coordinated green wave control for routes, to regional coordinated management.

Intelligent Control at a Single Intersection can achieve the following:

1. **On-demand Release for Each Direction/Phase**: Traffic signal release times are adjusted based on traffic volume in each direction and phase.
2. **Automatic Adjustment Based on Intersection Saturation**: The release mode is automatically adjusted according to the saturation level of the intersection.
3. **Reverse Overflow Control**: This prevents traffic congestion at the intersection and avoids "gridlocking."
4. **Maximized Intersection Efficiency**: Optimizes traffic flow to reduce congestion at intersections.

The **signal control system** monitors key trunk roads in real-time and, based on the saturation level and traffic movement conditions, automatically senses the required traffic flow mode for the entire route. The system then applies automatic adjustments to multiple control plans and strategies, achieving optimization effects like improved traffic efficiency and reduced delay times. The achievable route control strategies include:

1. **Real-time Adjustment Based on Traffic Flow Conditions**: The system adjusts the route

control mode in real-time based on current traffic flow.

2. **Maximized Efficiency at Bottleneck Intersections**: Ensures the maximum throughput efficiency at intersections that act as bottlenecks.
3. **Traffic Flow-Based Control Strategy Changes**: Adaptation of control strategies based on varying traffic volumes.
4. **Over-saturation Period Coordination Control**: Adjusting the signal timings to manage periods of high traffic saturation.
5. **Emergency Handling for Over-saturation**: Applying emergency control measures in case of excessive traffic flow.

By utilizing these control strategies and applying them according to different traffic conditions, the system aims to achieve intelligent and precise management of urban roadways. This leads to enhanced traffic efficiency and alleviates urban congestion.

2.4.4 Comprehensive Traffic Signal Optimization Control Platform

The platform provides integrated management and control for the system's phased array radar, edge computing control units, signal controllers, and other devices. It collects, statistics, analyzes, and performs comprehensive calculations on the data monitored by the radar. The platform visually and diversely displays urban traffic flow data, ranging from macro-level traffic conditions to micro-level vehicle flow dynamics.

In conjunction with the edge computing unit, the platform enables the comprehensive optimization control of multiple intersections, routes, and regions. This ensures a synchronized and efficient traffic signal control strategy across a broader network, enhancing overall traffic management and improving flow.



Figure 2.8: Comprehensive Traffic Signal Optimization Control Platform

2.5 Platform Detailed Introduction

2.5.1 Real-time Traffic Situation Monitoring

The platform can monitor real-time traffic conditions for roads by region, trunk roads, and intersections.

2.5.1.1 Regional Traffic Situation Monitoring

Real-time monitoring of the traffic conditions in a regional road network is possible. The platform can track real-time congestion index, travel speed, saturation, vehicle inflow and outflow data, and other metrics for the region. Based on these indicators, the platform ranks each region in real time and calculates the change rate compared to the previous statistical cycle.

By selecting a region, the system displays all real-time data for that region, including vehicle inflow and outflow curves for the day. It also shows the real-time congestion ranking of intersections within the region. The map interface offers a clear view of the region's boundaries, real-time traffic signal status at intersections, and the congestion status of

intersections and road segments.

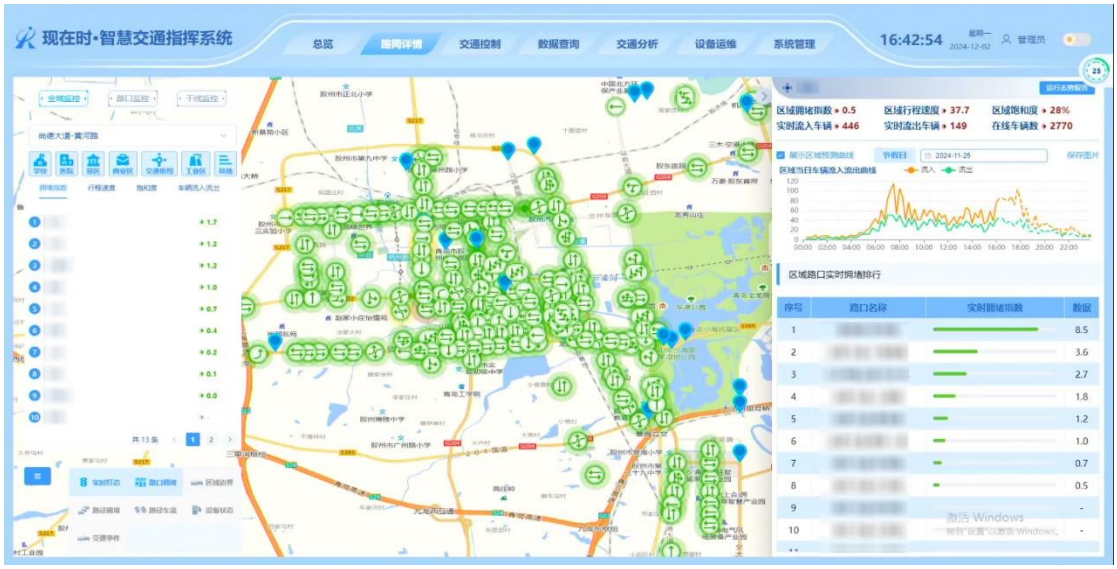


Figure 2.9: Regional Traffic Situation Monitoring

Inflow and Outflow Vehicle Flow Statistics for the Region:

By defining a region and setting boundary intersections, the platform can obtain the inflow and outflow vehicle flow data for the region. The platform displays the inflow and outflow vehicle flow through a curve chart, allowing a visual understanding of the traffic pressure within the region. The curve provides an intuitive representation of traffic volume changes, helping to assess congestion and flow dynamics in real time.

2.5.1.2 Trunk Road Traffic Situation Monitoring

Real-time monitoring of traffic conditions on trunk roads, including green wave routes, is available. The platform tracks congestion index, delay time ratio, queue length, travel speed, and other metrics for trunk roads. It can rank the trunk roads in real-time based on these indicators and calculate the change rate compared to the previous statistical cycle.

By selecting a trunk road, the system displays all real-time data for that road and presents a curve chart of data indicators for the entire day. This makes it easy to assess the traffic

situation. On the map interface, different colors are used to show the congestion status of road segments in real-time, as well as the current signal status at intersections. The system also shows the average vehicle speed on the road segment and the number of vehicles online.

Additionally, it provides detailed information on traffic conditions at each node of the trunk road and real-time operation data for the route.

For green wave routes, the system displays the dynamic release times at each intersection and offers video footage and release durations for the green wave direction.



Figure 2.10: Trunk Road Traffic Situation Monitoring



Figure 2.11: Green Wave Route Monitoring

2.5.1.3 Intersection Traffic Status Monitoring

The platform monitors the real-time traffic conditions at intersections, including service level, delay time ratio, traffic flow, saturation, queue length, congestion index, and other key metrics. It ranks intersections in real-time based on these indicators and calculates the change rate compared to the previous statistical cycle.

By selecting an intersection, the system displays detailed information, including all real-time data for the intersection. It also shows curve charts for traffic flow, queue length, and other indicators for the day. Additionally, on the map interface, the real-time service level of the selected intersection is displayed via its corresponding icon.



Figure 2.12: Intersection Traffic Situation Monitoring

2.5.1.4 Traffic Congestion Status Presentation

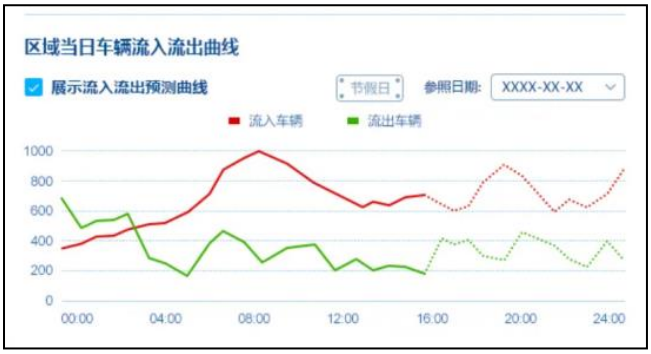
The real-time congestion status of intersections, road segments, and regions can be visually presented on the map interface using different colors: red indicates severe congestion, orange represents moderate congestion, yellow stands for light congestion, and green shows smooth traffic flow. Additionally, the congestion status can be saved to the backend, and in the traffic situation playback interface, historical traffic congestion data can be reviewed and played back.



Figure 2.13: Traffic Congestion Status Presentation

2.5.2 Traffic Data Prediction

The platform provides traffic data and trend prediction functionality. The prediction can be based on data from the same day of the previous week, the same day of the previous year, or any selected single day's data. The predicted data trends are displayed in the traffic situation interface as dashed lines. Predictions can be made for regional, trunk road, and intersection data.



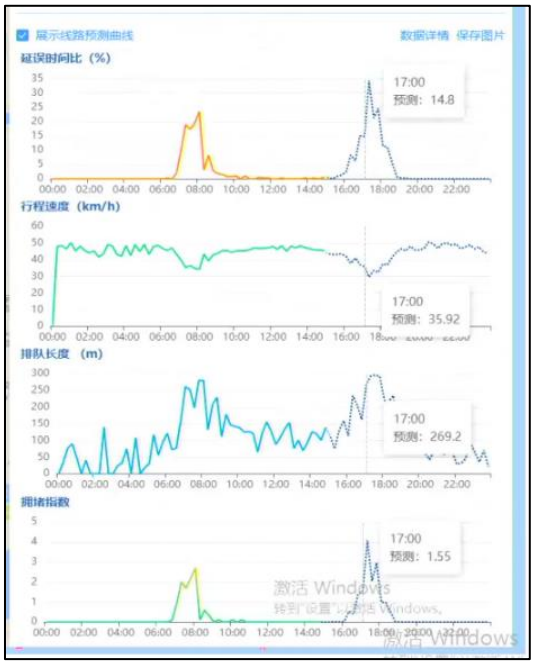


Figure 2.14: Traffic Data and Trend Prediction

2.5.3 Traffic Situation Playback

The platform allows playback of historical traffic conditions in a region. After selecting a specific date, the congestion status for that day can be played along the timeline, with road segments displayed in different colors to indicate the level of congestion.

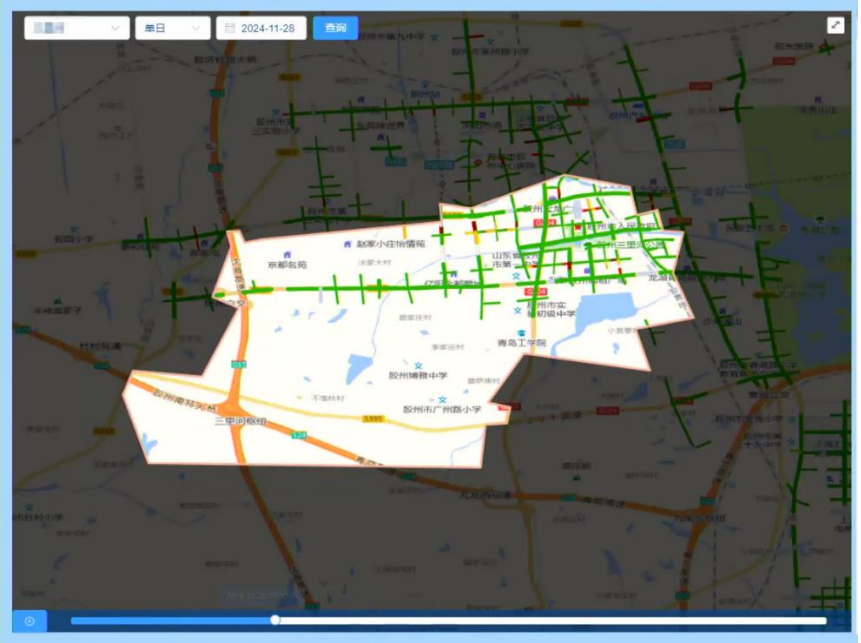


Figure 2.15: Regional Traffic Situation Playback

2.5.4 Full-Angle Intersection Simulation

The platform provides a real-time simulation displaying the traffic flow and vehicle trajectories detected by the radar. It presents the traffic status from all four directions of the intersection, while also showing the real-time signal light status for each direction. This allows a direct visual match between phase duration and traffic flow. Additionally, the platform can dynamically display real-time changing phase bar charts and recent historical data for each phase. It also offers curve graphs that visually present information such as intersection traffic volume and average speed.



Figure 2.16: Traffic Dynamic Information Query and Display

2.5.5 Historical Data Query and Display

2.5.5.1 Traffic Data Statistics and Storage

The platform can collect and store traffic data such as traffic volume, average speed, queue length, headway, and occupancy time, with statistics available at fixed time intervals or signal cycles. It can also record intersection signal timing information, including cycle duration and phase duration. These data can be saved and exported, with customizable data retention periods.

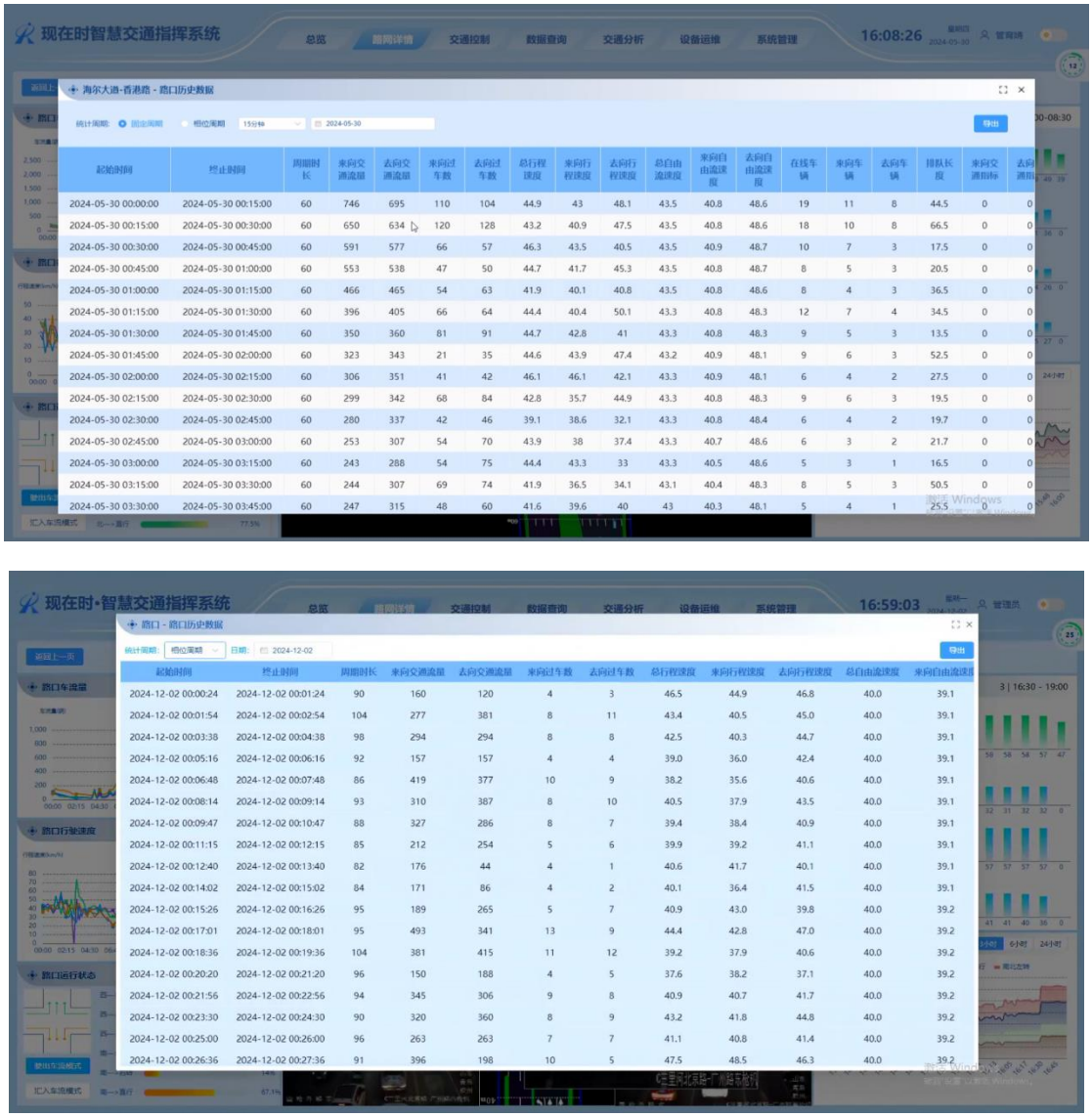


Figure 2.17: Traffic Data Statistics and Storage

2.5.5.2 Intersection Data Query and Display

The platform provides a historical traffic data query function for intersections. By selecting a specific time range and intersection, users can view various traffic indicators for the intersection within that time period, including traffic volume, saturation, turn ratio, average speed, queue length, congestion index, and signal timing data. These data are visually displayed through charts.



Figure 2.18: Single Intersection Historical Data Query and Display

2.5.5.3 Main Line Data Query and Display

The platform supports viewing historical traffic data for main lines. After selecting a time period, users can view various traffic data for the selected main line, including traffic volume, travel speed, congestion index, and traffic data for intersections along the line. The platform also supports playback of the traffic conditions at different times along the line.



Figure 2.19: Main Line Historical Data Query and Display

2.5.5.4 Area Data Query and Display

Supports viewing historical traffic data for a selected area. After selecting a time period, users can view various traffic data for the chosen area, including the number of vehicles flowing in and out, congestion index, and average speed, as well as traffic data for each intersection within the area. It also supports playback of historical traffic conditions at different times within the area.



Figure 2.20: Area Historical Data Query and Display

2.5.6 Traffic Data Comparative Analysis

2.5.6.1 Single Point and Mainline Data Comparative Analysis

The system allows for comparison of data metrics at the level of intersections and mainlines. It can compare multiple days' data for a specific intersection, with the option to choose directions. Additionally, data from multiple intersections on the same day can be compared, and the same applies to mainline data. All comparisons are presented in graphical format.

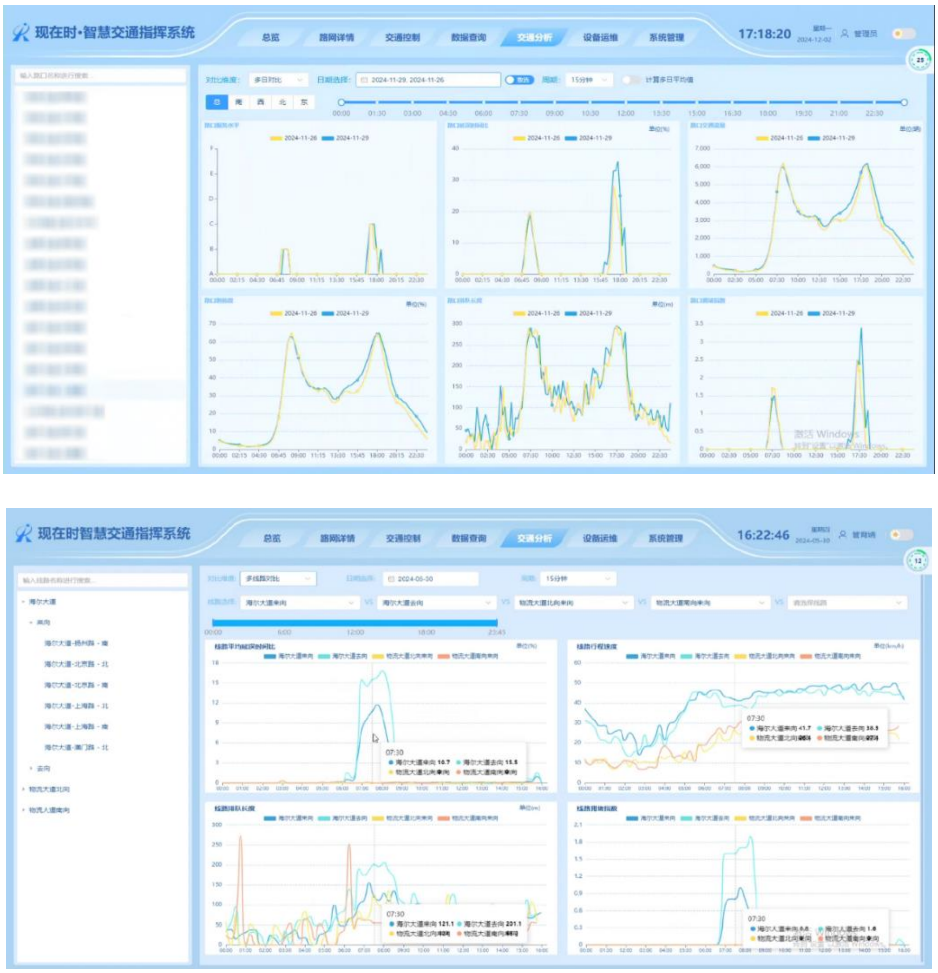


Figure 2.21 Traffic Data Comparative Analysis

2.5.6.2 Regional Traffic Operation Status Report

The system provides the functionality to generate a regional operation status analysis report, supporting the generation of a report document for a specific region and time range. The report content includes: an overview of the selected region within the specified date, the average number of vehicles online in the region, the number of vehicles flowing in and out, the region's average congestion index, average travel speed in the region, the congestion ranking of intersections within the region, and data for congested intersections. This provides macro-level regional data analysis to assist in traffic decision-making.

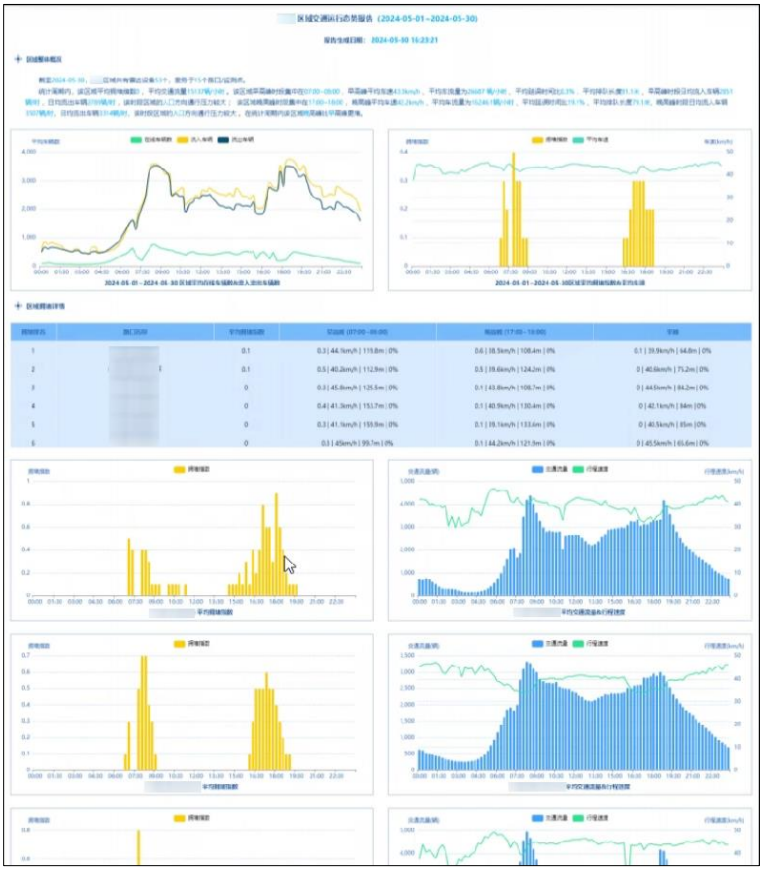


Figure 2.22 Regional Traffic Operation Status Report

2.5.7 Traffic Abnormal Event Monitoring

Traffic congestion, intersection overflow, queue overrun, green light empty release, and other abnormal traffic events can be reported. The abnormal information can be displayed on the map interface at the corresponding intersection with icons. Additionally, the historical traffic events at the intersection can be reviewed.



Figure 2.23 Traffic Event Monitoring

2.5.8 Device Management Functionality

The platform can manage radar, edge computing control units, and signal controllers. The device management information includes the following: associated area, associated intersection, device IP, device online status, etc. All devices can be displayed in a list format or on a map.



Figure 2.24: Device Management

2.5.9 Device Monitoring and Maintenance

The system can display the overall online status of devices as well as the online status of devices within specific regions. When a device goes offline, an alert is triggered via a popup window. The system also allows filtering to display all offline devices and can prioritize them for attention. Abnormal device statuses can be visualized on the map through different charts.

The system also monitors the operational status of key devices. In case of power failure at an intersection, device disconnection, or line faults, the system will automatically trigger an alarm and send notifications to maintenance personnel. Additionally, it monitors phase and cycle operation status.

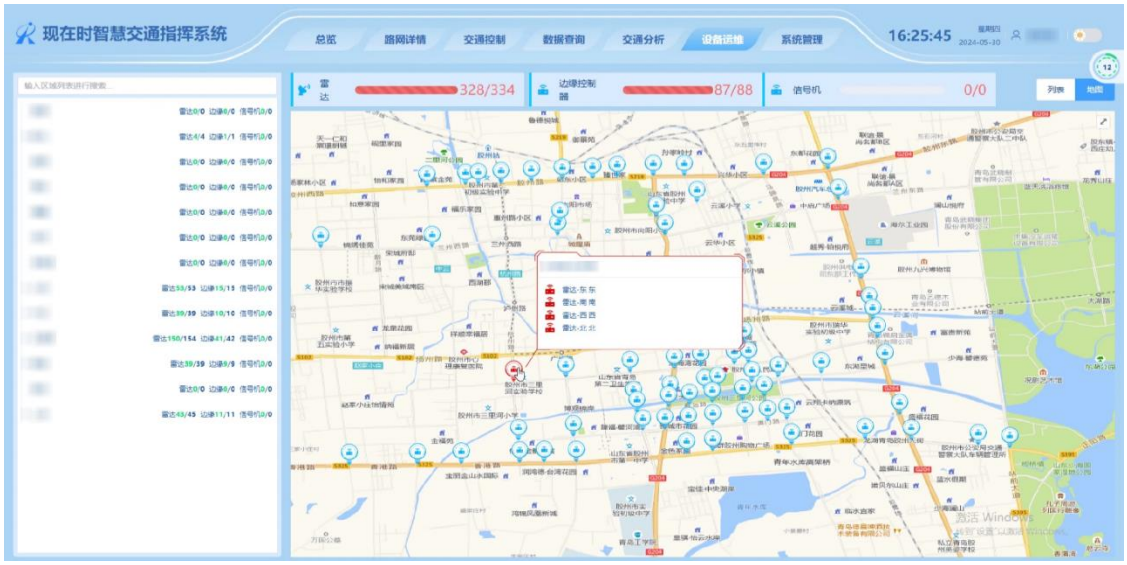


Figure 2.25: Device Monitoring and Maintenance

2.5.10 Road Network Configuration and Management

The basic information of intersections, trunk roads, and areas displayed on the platform can be modified through the road network management module.

For intersection basic information configuration, intersections can be added at

corresponding locations on the map. Relevant information for the intersection can be configured, including intersection name, controller type, signal light type, radar information, camera information, lane diagrams, etc.

For trunk road basic information configuration, a route can be formed on the map by connecting intersections, and the route information can be edited or deleted.

For area basic information configuration, areas can be drawn on the map. The type of area can be selected (such as commercial area, school, hospital, industrial park, etc.), and boundary intersections for sub-areas can be selected. The directions for vehicle flow into and out of the area can also be set.



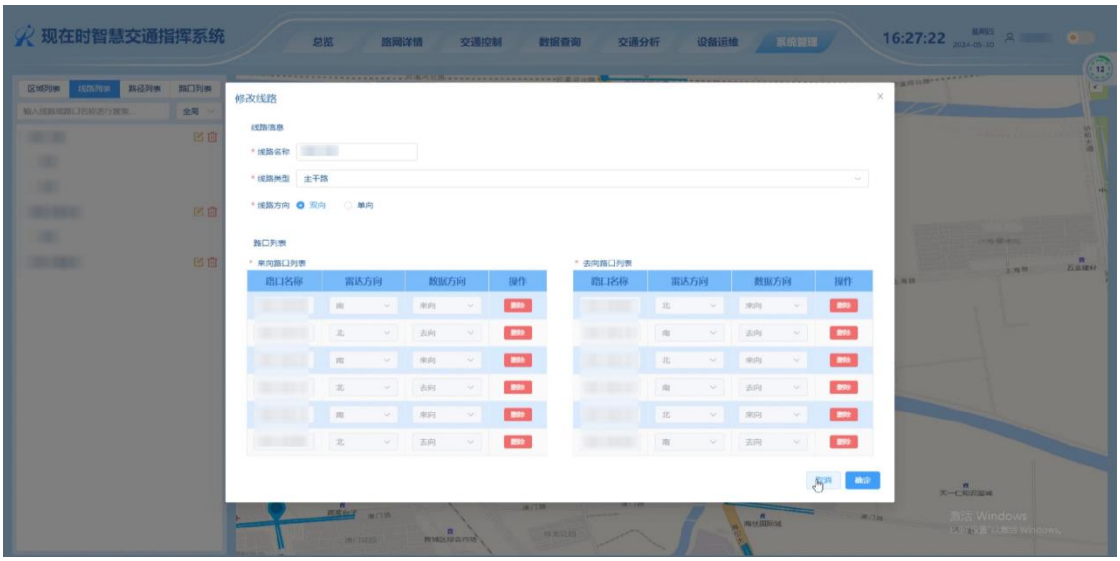


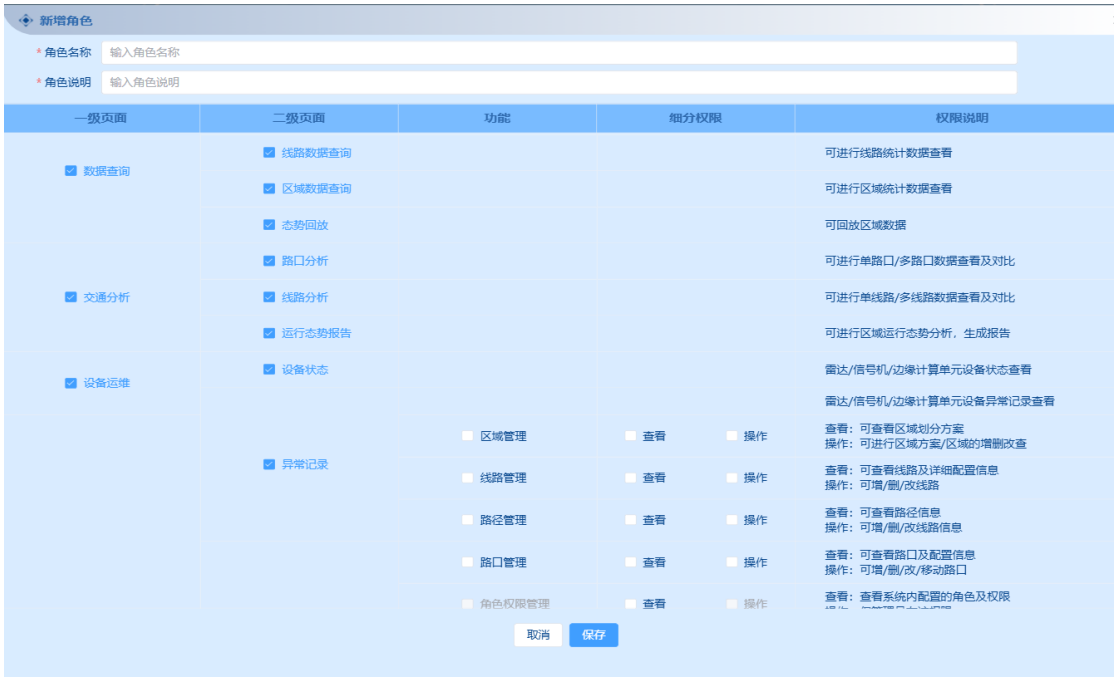
Figure 2.26 Road Network Configuration and Management

2.5.11 System Configuration and Management

- **Role Permission Management**: Different roles can be distinguished by their operation and viewing permissions within various system modules.
- **Organizational Structure Management**: Differentiates organizations under the same entity and isolates data visibility. By assigning visibility permissions for regional and intersection data to different organizations, users are assigned to specific organizations, ensuring data isolation.
- **User Management**: Allows centralized management of system users, including their usernames, passwords, roles, and organizations.
- **Map Layer Management**: Controls the display order and coverage area of various icons within the map panel.
- **User Log Viewing**: Records and displays all user operations within the system, enabling traceability of issues like user errors.
- **System Backup Management**: Controls the retention period of various traffic data generated within the system, supports manual adjustments for data retention, manual

backups of system data, and the ability to download and view system data.

- **Server Performance Monitoring**: Monitors key performance indicators of the servers deployed for the system, such as CPU usage, memory consumption, disk usage, and network transmission. It provides a graphical display of these indicators' usage over the past 7 days, with floating windows for these metrics.
- **Account Personalization Configuration**: Configures certain system parameters for the currently logged-in user, affecting their individual experience within the system.
- **System Personalization Settings**: Configures global system parameters, including system name, server time calibration, and regional display schemes, impacting all logged-in users.



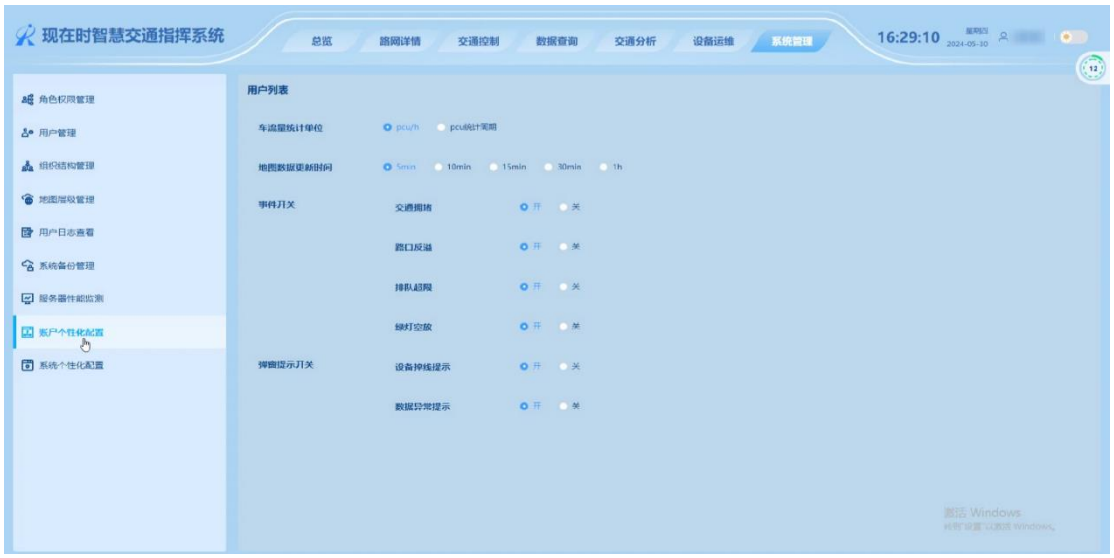


Figure 2.27 System Configuration and Management

2.6 System Application Features

2.6.1 Single-Point Intelligent Control

Based on real-time traffic flow information obtained from the phased-array radar detectors, a control scheme matching the traffic demand is dynamically generated. The phase time is adjusted in real-time to achieve precise second-level control. Under saturated or oversaturated conditions at intersections, the queue length is dynamically reduced to prevent vehicles from spilling over to upstream intersections. When the intersection is not saturated, the system reduces green light empty release and intersection delay, avoiding secondary vehicle queuing. This achieves "zero empty release, minimal flow restriction," maximizing the intersection's traffic efficiency.

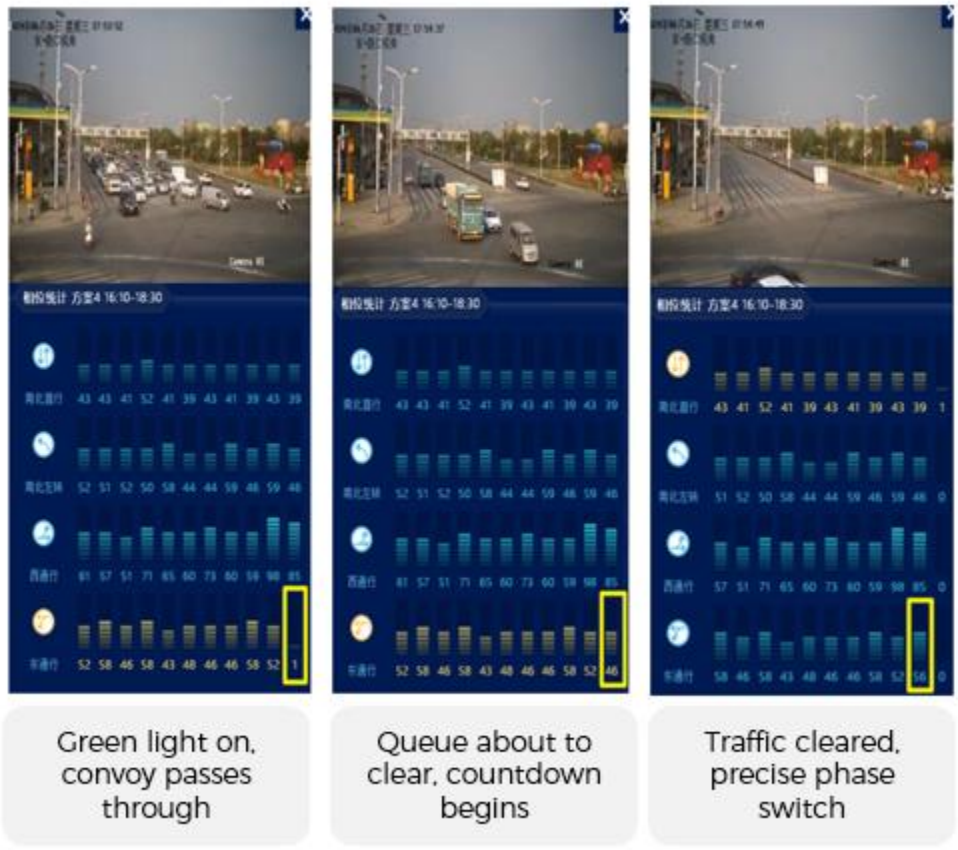


Figure 2.28: Single-point intelligent control

2.6.2 Reverse Overflow Control

Real-time monitoring of the traffic conditions in the exit lanes of intersections. When congestion is detected at the exit or when downstream queued vehicles are about to overflow, the current phase of green light is promptly terminated. Effective measures are taken to block subsequent vehicles from entering the direction, preventing internal vehicles from "knotting" and causing congestion overflow to the upstream, which could lead to a continuous spread of congestion.

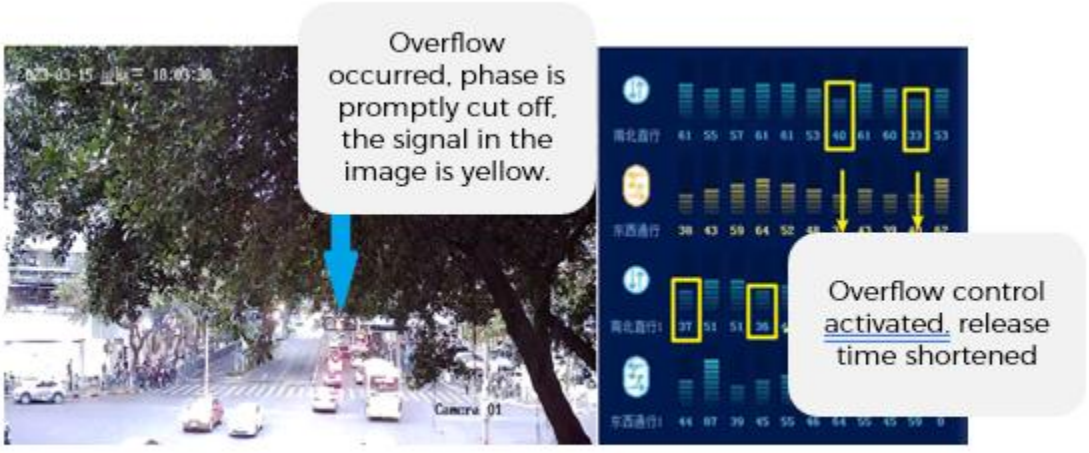


Figure 2.29: Reverse Overflow Control Diagram

2.6.3 Mainline Coordination Control

Based on traffic flow saturation, the control strategy is adjusted in real time. Under unsaturated conditions, dynamic green wave coordination is implemented for the mainline, allowing vehicles to pass without stopping, preventing congestion in the intersection center. The public cycle time, phase time, and phase differences change in real time with traffic flow. Under saturated traffic flow conditions, coordination control of line congestion is implemented to balance queue lengths and prevent excessive queuing. In the case of oversaturated traffic flow, the mainline features gradual entry and fast exit, combined with reverse overflow control, to prevent queue overflow and enable overall dynamic adjustment between intersections. Through real-time traffic status interaction between intersections, the central server executes regional algorithms, dynamically allocating scientifically reasonable control plans to each intersection.

For example, in a city project, a certain route installed this traffic control system across its entire length. Based on the actual needs of each intersection, dynamic green wave coordination was implemented, reducing travel time by 26%, while ensuring smooth

passage for side roads without congestion, balancing fairness and efficiency.

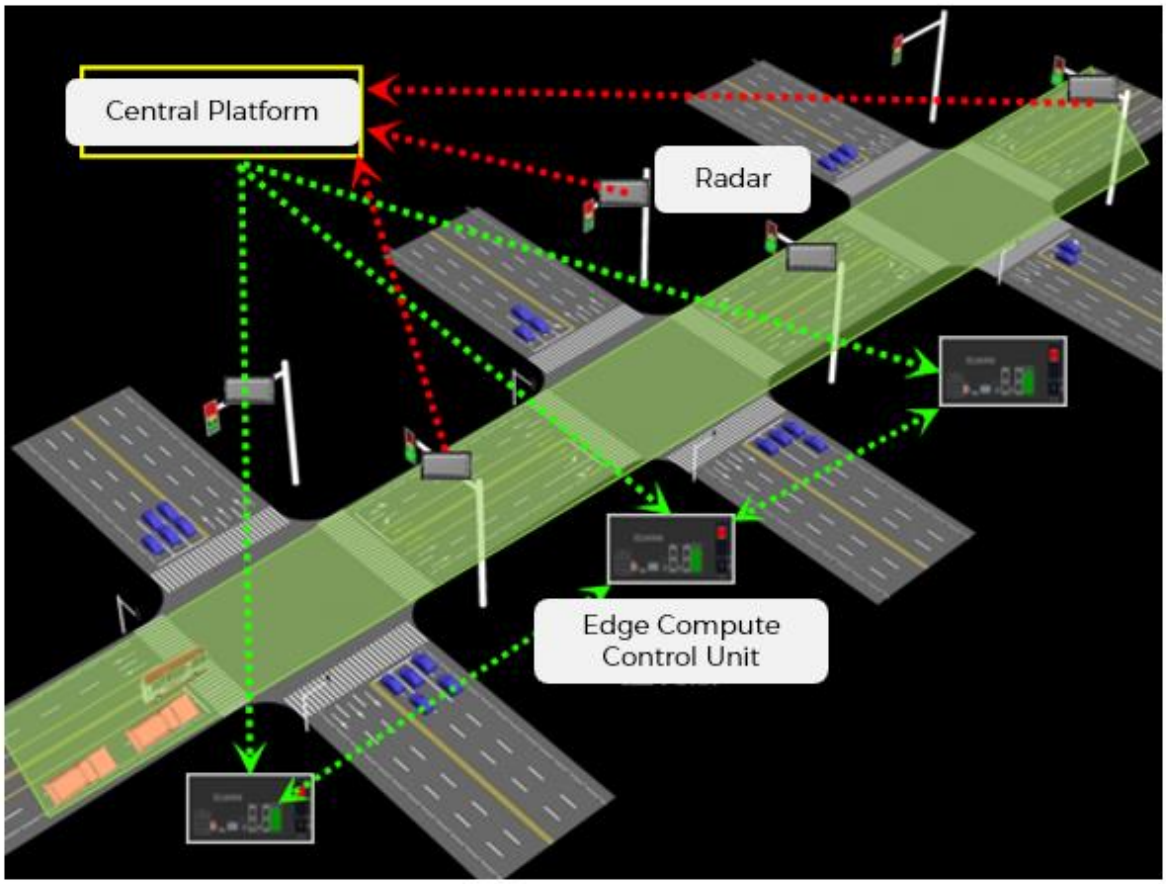


Figure 2.30: Mainline Smart Green Wave

2.6.4 Regional Coordination Control

The system uses "gradual entry, fast exit" as the main approach to alleviate congestion, fully leveraging the advantages of phased array radar, which can detect long distances and measure accurately. Through big data analysis, it has the ability to control regional traffic lights, enabling integrated management and coordination of intersections across the entire area to maximize traffic efficiency over a large range. It can control the flow of vehicles entering and exiting specific areas based on traffic conditions in the main urban area or a

particular region. When traffic congestion occurs within the region, or when key intersections become saturated or oversaturated, the system controls the vehicles entering the area while accelerating the flow of traffic exiting the area, preventing further congestion. When congestion alleviates or the saturation of key intersections drops to a certain range, the control is lifted.

For example, during holidays, major events, or traffic accidents, when traffic flow on roads or within areas suddenly increases or becomes abnormal, the system will promptly detect these changes and adjust based on actual traffic flow, pushing abnormal information to traffic managers in real time.

Additionally, through this system and supporting traffic guidance systems and urban frequency broadcasting systems, traffic flow in major functional areas is directed to main roads, and with the established single-point intelligent control and mainline coordination control, quick evacuation, precise release, reverse overflow prevention, millisecond-level perception, and second-level response are achieved.



Figure 2.31: Regional Coordination Control

3. Equipment Requirements

3.1 Front-end Intersections

The main equipment required for installation at front-end intersections includes phased array radar, edge computing control units (ECCU), fault detection modules, and supporting cameras. Table 3-1 illustrates the quantity of front-end intersection equipment needed, using cross intersections and T-intersections as examples.

Table 3.1 Front-end Intersection Main Equipment Requirements

Intersection	Microwave Radar (pcs)	Camera (pcs)	Edge Compute Control Unit (pcs)	Fault Detection Module (pcs)
** Intersection	4	4	1	1
** Intersection	4	4	1	1
Total				

3.2 Command Center

The command center server uses standard general-purpose servers (which can also be repurposed), with the specific number and performance of servers depending on the number of intersections. It is also equipped with an intelligent traffic signal comprehensive optimization control platform, which is responsible for managing and controlling the

equipment, optimizing intersections, coordinating regions, and displaying traffic conditions.