Chapter 7
Intelligent Traffic Management and Control Technology

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Transportation system is a complex and huge system which is composed of people, vehicles, roads, and their environment. Therefore, it is limited to solving traffic problems unilaterally only from people, vehicles, and roads. It is necessary to start from the point of view of the system, comprehensively consider factors such as people, vehicles, and roads, and apply various advanced technologies and scientific methods to traffic management and control. On the one hand, the "node" in traffic systems, such as people and vehicles, has a full understanding of the system. On the other hand, the traffic managers can understand and monitor the state of the traffic system in real time, and make scientific management and optimal regulation, so that the system can work at maximum efficiency and realize the intelligence of the whole system.

7.1 Overview of Intelligent Traffic Management System (ITMS)

7.1.1 Concept and Development Status of ITMS

Intelligent Traffic Management System (ITMS) is an important part of intelligent transportation systems. Intelligent traffic management is defined as follows: According to the urban road traffic information collection, processing, release, and decision-making process, various advanced technologies and scientific methods are used to achieve the automation, modernization, and intelligence of traffic management. The system constructed to achieve the goal of intelligent traffic management is

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ITMS. The related technologies used in the realization of intelligent traffic management are called intelligent traffic management technology, which includes not only various IT technologies of electronic and information processing, but also related theories and methods of traffic science, system engineering, and management science.

The development of ITMS not only promotes the improvement of urban traffic management, but also strengthens the effective coordination between various traffic modes through information technology, starting from improving the transport capacity and transport efficiency of existing traffic facilities to enhance the control capabilities of road traffic and rapid response and disposal capabilities for emergencies. By improving the traffic efficiency and load-carrying capacity of the road network to alleviate traffic congestion, reduce traffic accidents, reduce time delays, energy consumption, and exhaust emissions caused by traffic congestion, conditions are created for the sustainable development of cities. At the same time, it also promotes the development of transportation and related industries, which is of great significance to the construction of urban modernization.

The ITMS system in the United States integrates highway and urban traffic management to reduce travel time, improve efficiency, better automatically detect accidents and establish accident response system. Metropolitan Area Guidance Information and Control (MAGIC) is a typical ITMS system. MAGIC is an important project of ITMS in New Jersey. Its goal is to reduce road traffic congestion, thereby reducing vehicle exhaust emissions. MAGIC includes content such as road monitoring, traffic management, traffic information services. Various sensors installed in the MAGIC system receive information, which is processed by the main computer to control road traffic conditions and display relevant data and deal with accidents. The expert system provides alternative paths to vehicles and recommendations to mitigate traffic congestion. The MAGIC system also uses highway information broadcast to provide service information for vehicle drivers, inform traffic, road and weather conditions, and recommend path selection. The accident detection system uses the data from the road monitoring system to automatically alarm for possible accidents after calculation by the computer software system. In addition, MAGIC can use the ramp monitoring system to detect the occupancy rate of the ramp and the vehicle speed on the ramp of the loop coil, and cooperate CCTV cameras monitor and control vehicles entering the ramp area.

Japan's Universal Traffic Management System (UTMS) was built in 1993 to adapt to the increasing demand for traffic in Japan, and is committed to achieving a safe, comfortable, and environmentally friendly traffic society. The key of UTMS is to realize the interactive two-way communication between the vehicle and the control center. The communication system uses infrared beacon to accurately transmit the control information of the management center on traffic demand and traffic flow to the driver, and comprehensively manage the traffic flow to avoid traffic congestion and ensure the safety of the vehicle. UTMS is mainly composed of six systems:

- The integrated traffic control system is set in the traffic control center, which is the information center for two-way communication with the vehicle device, and the traffic signal is controlled through this system.
- Advanced traffic information system, which can use the existing mobile communication network and vehicle communication media in UTMS to realize bidirectional information communication in traffic management.
- Dynamic path guidance system, which can guide vehicles to reach the destination along the optimized path, so as to achieve the purpose of dispersing vehicle driving routes and reducing traffic congestion.
- Vehicle driving management system, by accurately providing the traffic police with the driving positions and road conditions of buses, taxis, and trucks, etc., and through the signal management at the intersection, it helps vehicles to drive effectively and promotes smooth traffic.
- Public transit priority system, which can ensure the priority of bus using the road by controlling the priority signal and setting the priority route.
- Environmental protection management system, through which the traffic control center can provide traffic information such as weather and air quality to vehicle drivers and travelers through this system, and can implement vehicle operation management by controlling traffic signals to reduce exhaust, reduce traffic noise pollution and protect the environment.

Although China's intelligent traffic management system started late, after nearly two decades of unremitting efforts, considerable progress has been made. At present, domestic first-tier cities such as Beijing, Shanghai, Shenzhen, etc. have built ITMS with intelligent control center, control system, and control platform as the core, which integrates Advanced Traveler Information System (ATIS), Advanced Traffic Management System (ATMS), Advanced Public Transport System (APTS), Advanced Vehicle Control System (AVCS), Freight Management System, Electronic Toll Collection System (ETC), Emergency Medical Service (EMS), and other application subsystems. It has a high level of application in traffic information collection, traffic control, grid vehicle recognition, traffic guidance, traffic incident processing, intelligent traffic violation management, video surveillance, and other terms.

7.1.2 Framework and Function of ITMS

As an application system for traffic management department, ITMS takes ATMS and ATIS applied in urban road traffic management as the main body, and is interrelated with other ITS subsystems. The overall framework of ITMS is shown in Fig. 7.1.

ITMS mainly includes the following components and functions.

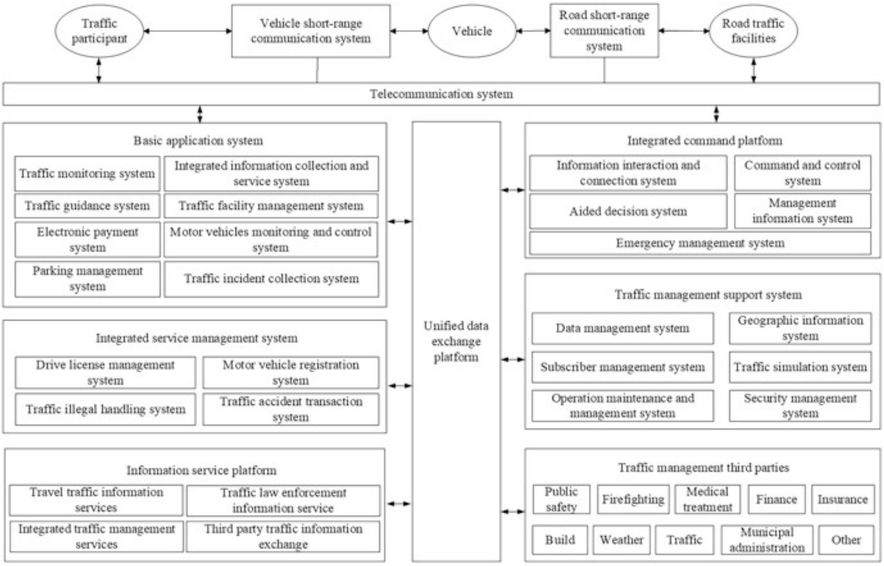


Fig. 7.1 ITMS overall framework

7.1.2.1 Basic Application System

1. Basic traffic data processing: Through data and external equipment, the collection of traffic static data is realized, and the information including urban map, population, economy, and road resources. The digital processing of text data is realized through the central server, and the basic database is obtained, and the data storage and reading can be realized.
2. Traffic status monitoring: The real-time traffic situation on the road is mastered by the on-road equipment, and information including passing traffic data, traffic flow data, meteorological information, and traffic events is collected to realize the comprehensive monitoring of the road in the center.
3. Traffic organization and management control: Realize the collection of traffic travel demand data, complete the analysis of historical traffic flow data, and optimize the traffic organization scheme according to the traffic situation. Through the analysis and judgment of the existing traffic data, the traffic situation can be predicted, and the priority control of public transport and other special vehicles can be realized.
4. Motor vehicle investigation and control: Carry out the investigation and control of illegal vehicles, and can give feedback within the specified time. It can realize early warning management and analyze vehicles trajectory.
5. Electronic toll collection and electronic payment: The system can provide an interface to realize the functions of online payment of certificates, vehicle inspection, traffic illegal fines, and other related business expenses, to realize the automation and convenience of payment.

7.1.2.2 Integrated Command Platform

1. Emergency command: In a state of emergency, effective control of the situation can be achieved through the ITMS, including traffic dispersion for large-scale activities, traffic congestion command and dispatching, traffic incident disposal, plan management and evaluation, video connection with the scene, control and dispatching of special service tasks, etc.
2. Traffic safety situation assessment: It can evaluate and warn the traffic safety status of the road network, road sections, and important nodes. It can judge the operation status of the road network, road section, and important nodes, and analyze the influence of the weather situation on traffic. Road safety audits can be conducted to comprehensively assess the safety situation.
3. Service management: Through the ITMS, the internal service status of the traffic police can be managed, and can realize the positioning of police officers and police vehicles, as well as the manual and automatic arrangement and assessment of service, and the emergency management and special service task management can be completed.

7.1.2.3 Integrated Business Management System

1. Basic information business management: The management of motor vehicle information, driver information, and road traffic illegal accident processing information can be realized, and the query of traffic management information such as public security network and police traffic can be realized.
2. Comprehensive business analysis: The driver information business, vehicle information business, traffic accident information business, and traffic illegal handling information business are analyzed. It can complete the research and judgment of the traffic accident situation and traffic illegal situation, and prevent road traffic accidents through research and judgment.

7.1.2.4 Information Service Platform

1. Road traffic information release for travelers: The real-time information of road traffic can be released to the traveler through the terminal, which can respond to the query request of the terminal user, release the real-time progress of road traffic control at any time, and provide parking guidance and reservation service.
2. Comprehensive traffic safety services for travelers: Drivers can query basic information of drivers and motor vehicles, illegal information of drivers, and motor vehicles through the ITMS. System can be accessed through the terminal to achieve the relevant business processes and laws and regulations query.
3. Information exchanges for third parties: Road maintenance departments and construction departments can collect and transmit information through the system. It can realize the collection and transmission of meteorological and

environmental information. First aid resources and fire resources can be collected and updated. It can also provide traffic information services to transportation, fire protection, construction, financial insurance, and other related business units.

7.2 Typical ITMS and Application

ITMS involves a wide range of areas, and there are many related application systems. In the actual traffic management, common typical application systems mainly include intelligent traffic monitoring system, electronic police system, intelligent public transport management system, parking guidance system, and emergency management system. This section will describe the typical application systems in detail.

7.2.1 Intelligent Traffic Monitoring System

7.2.1.1 Overview of Intelligent Traffic Monitoring System

Intelligent traffic monitoring system is currently one of the most widely used systems in the field of traffic management. Intelligent traffic monitoring system can be divided into three parts according to the information flow, namely information collection, information processing and information release. Monitoring information collection can be regarded as an information management system, including information collection, transmission, and classification storage. Information processing is the key part of the whole intelligent traffic monitoring system. According to various data and information collected and detected, information processing provides control strategies through processing, analysis, and judgment, and regulates the relevant traffic operation through corresponding equipment. As the terminal of information flow output of intelligent traffic monitoring system, information release shoulders the task of dialogue with the driver. For the control strategy and warning information of intelligent traffic monitoring system can be transmitted to the user in time, it is necessary that information release can affect the user in a timely manner through various ways. Intelligent traffic monitoring system is suitable for highway, important bridge tunnels, urban road traffic management, and other occasions.

7.2.1.2 Composition and Function of Intelligent Traffic Monitoring System

Intelligent traffic monitoring system has practical application in both urban roads and highways. The urban traffic monitoring system in real time detects the traffic flow and vehicle traffic conditions of the main traffic arteries and intersections. According to the feedback information of each monitoring point, it predicts the possible blockages in some traffic arteries and intersections, so as to adjust and induce the traffic flow in time, reduce the traffic congestion, maximize the utilization rate of the road system, and create a safe and comfortable road traffic environment. The highway monitoring system implements the traffic control scheme through the detection of traffic flow, the monitoring of traffic conditions, the environmental meteorological detection, and the monitoring of operation conditions of the whole highway, so as to achieve the purpose of controlling traffic flow, improving traffic environment, and reducing accidents, so that the highway operation can achieve higher service levels.

1. Urban Traffic Monitoring System. The development direction of modern urban traffic monitoring is mainly reflected in network and intelligence. In urban traffic monitoring system, modern computer technology, electronic technology and information technology are comprehensively used to realize intelligent management. A complete urban road traffic monitoring system is actually an integration of multiple subsystems. Based on the characteristics of urban road traffic, the composition of modern urban traffic monitoring system is shown in Figure 7.2.

   Traffic Monitoring Subsystem: Traffic monitoring subsystem consists of a front-end image collection unit, a signal transmission unit, and a central control unit. Its function is to transmit the situation of each intersection to the central control unit in real time and quickly, so that the traffic control management personnel can observe the real situation of each intersection in the city at any time, so that the managers can make correct judgments and provide information support for road traffic guidance.

   122 Alarm Accepting and Processing System: 122 alarm accepting and processing system consists of telephone communication dispatching subsystem, telephone digital recording subsystem, data management subsystem, head terminal subsystem, and electronic map subsystem (optional). Among them, the communication dispatching subsystem and the digital recording subsystem can run on the same computer, and the alarm subsystem and the electronic map subsystem can also run on the same computer.

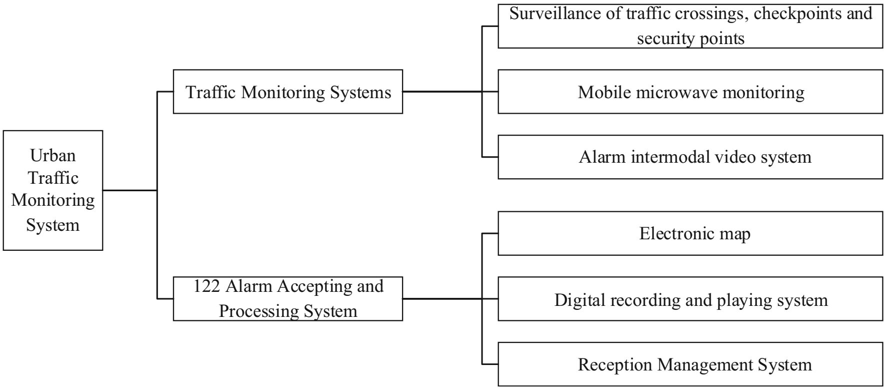


Fig. 7.2 Function Composition of Urban Traffic Monitoring System

Command Center Computer Management System: The main task of the command center computer management system is to connect the above independent application systems together to achieve orderly management, information dissemination and information communication for higher authorities and society. The traffic command center is the center of traffic monitoring system, which needs to be integrated through traffic integrated information management system.

2. Freeway Traffic Monitoring System. The main purpose of freeway traffic monitoring system is to provide effective means of traffic management, control, monitoring and inducing traffic operation for freeway. It collects various traffic data through the use of advanced electronic technology, helps the freeway management department to grasp the various data and information of the traffic flow in time, processes and analyzes the information through computer software, forms control strategies, and issues various control commands in a timely manner. Traffic information, deal with various traffic accidents and congestion phenomena, divert traffic flow, formulate effective measures to reduce traffic accidents and traffic congestion, and provide various services to relevant departments in a timely manner (including rescue of injured persons, dragging off faulty vehicles, repairing damaged roads and damaged equipment, etc.) to ensure the safety and smoothness of freeways.

The working principle of freeway traffic monitoring system is to collect freeway road, traffic, accidents, and other information through vehicle detectors, emergency telephones, closed-circuit television, and patrol vehicles along the road, and transmit them to the monitoring center for calculation, processing, and recording. At the same time, the road utilization, vehicle operation, and equipment working state are displayed by using the map plate, graphic display, Chinese character display, television, and other facilities of the monitoring center. Based on the above information, the on-duty personnel put forward the control scheme, issued the necessary commands or instructions, and transmit warnings or suggestions to road users through the variable intelligence board and variable speed limit signs set along the line.

The operation of traffic monitoring system especially emphasizes the role of monitoring center. Under normal traffic conditions, the information processing computer of the monitoring center conducts analysis according to traffic flow and meteorological conditions to form a decision-making control scheme, and uses variable information boards and variable speed limit signs to guide and control traffic. In the case of abnormal traffic conditions, the information processing computer of the monitoring center displays the corresponding control scheme to the operator according to the data processing results. After the operator confirms the event according to the field image, emergency telephone, patrol car, etc., monitoring center issues control instructions and induces control scheme.

The freeway monitoring system is mainly composed of a traffic information collection system, a central control system, and an information release system.

Traffic Information Collection System: The ways of information collection in traffic information collection system are manual and automatic. The main information collection methods are meteorological detection device, vehicle detection device, closed-circuit television, emergency telephone, radio equipment, etc.

Central Control System: The central control system is an intermediate link between the information collection system and the information release system, which is the core part of the monitoring system. Its main functions is to perform real-time operation, processing, and analysis on the data from the information collection system. According to the analysis results, the control scheme is decided, the corresponding control command is issued, and the event handling is commanded. Traffic conditions of each main road section are monitored through the closed-circuit television system. Responsible for communication within the jurisdiction area. Real-time monitoring of the working status of the entire system equipment. The central control system is usually composed of a computer system, an indoor display equipment and monitoring system console.

Information Release System: The information release system is a facility installed on freeways to provide road traffic information and guidance control instructions to road users, as well as to provide help orders or road traffic information to management, rescue departments and the society. Its main equipment includes variable information and variable speed limit signs, lane control signs, command telephones and traffic broadcasting systems, etc. The system mainly includes the following aspects, providing information to road users, such as traffic congestion, accident alarm, weather, road construction, etc. Providing advice or control commands to road users, such as the best driving route, the best speed limit, lane control signal, ramp control signal, etc. Providing information to the management and relief departments and providing information to society.

7.2.2 *Electronic Police System*

7.2.2.1 Overview of Electronic Police System

As a modern high-tech traffic management means, electronic police can not only effectively solve the contradiction between the police force and the management task, monitor the road 24 h a day, and improve the awareness of traffic participants to abide by the law consciously, but also effectively regulate law enforcement behavior and promote law enforcement justice. It also provides a powerful reconnaissance means for combating illegal and criminal behaviors such as avoiding annual inspection, causing accidents and escaping, and stealing and robbing vehicles. Because the electronic police system can work all the time, the blind spots of road traffic management in time and space are eliminated to a certain extent, the monitoring period and scope of traffic management are expanded, and the illegal behavior of motor vehicle drivers is effectively suppressed. It has been recognized by road traffic management departments at all levels and is widely used in cities at all levels in China.

7.2.2.2 Composition and Function of Electronic Police System

1. System Composition: The electronic police system consists of three parts: the front-end subsystem, the network transmission subsystem, and the back-end management subsystem. It can automatically capture, record, transmit, and process traffic violations such as running red lights, pressing lines, retrograde, not following the guiding lanes, illegal parking, not wearing seat belts, and talking on mobile phones while driving. At the same time, it also has the function of card port and can record the traffic information in real time.
   The front-end subsystem is responsible for completing the collection, analysis, processing, storage, and upload of the front-end data, which is mainly composed of electronic police capture unit, light compensation unit, video analysis and recording unit and other related components. Intersection traffic illegal information and bayonet information are transmitted by IP. The front-end subsystem includes the following parts.

   (a) Image detection plays the role of vehicle induction in the system, mainly including loop coil detector, video detector, ultrasonic or microwave (radar wave) detector, infrared detector, etc.
   (b) Image capture plays the role of image capture in the system, mainly including camera and video cameras.
   (c) Image collection is to digitize analog video images. Utilizing multichannel video image collection card makes the multichannel analog video image convert into digital video information after a multiplexer, A/D converter, cropping, and compression coding. Video compression coding methods commonly used internationally include MJPEG, Wavelet (wavelet transform), MPEG-1 (such as VCD), MPEG-2 (such as DVD), and MPEG-4, etc.
   (d) Image processing includes two parts, control host and system application software, which play the role of control, image recognition, storage, and management in the system.

The network transmission subsystem is responsible for the transmission and exchange of data, pictures, and videos, and the construction of video private network. The intersection LAN is mainly composed of field industrial switches, point-to-point bare optical fiber and optical fiber transceiver. The central network is mainly composed of access layer switch and core switch.

The back-end management subsystem is responsible for the aggregation, processing, storage, application, management, and sharing of relevant data within the jurisdiction, which is composed of central management platform and storage system. The central management platform is composed of servers carried by platform software modules, including management servers, application servers, web servers, picture servers, video servers, and database servers, etc.

2. System Functions. Red Light Running Monitoring and Recording Function. The electronic police system automatically perceives the traffic light signal through video triggering. At the red light signal, when the vehicle passes, the system host will quickly detect these changes, and judge whether there is a vehicle passing by

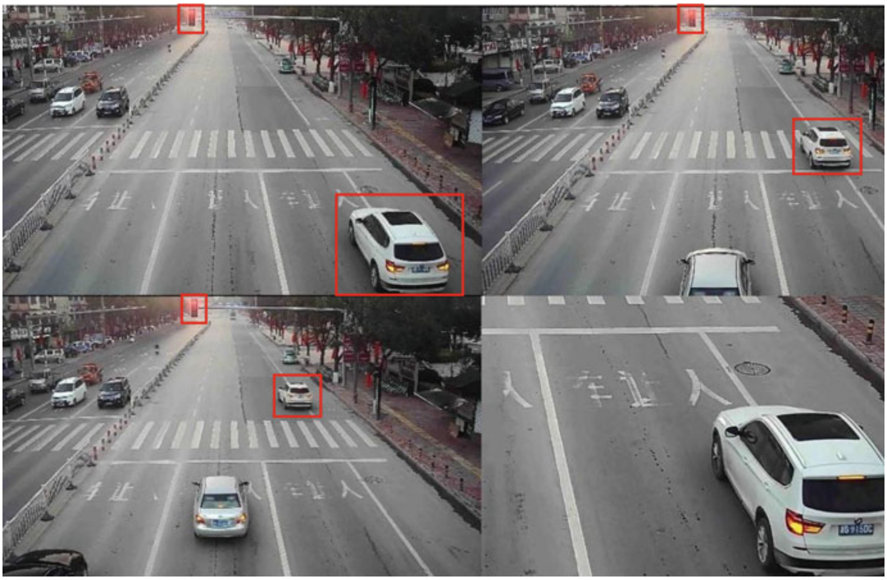


Fig. 7.3 Snapshot of vehicles running red light

analyzing and processing this change. When it is detected that there is a vehicle passing under the red light state, it will automatically capture a picture of the illegal vehicle, take three pictures of the illegal process of the vehicle and a close-up high-definition picture (Figure 7.3). As shown in Fig. 7.3, the image can clearly distinguish the red light state, red light time, parking line, illegal time, illegal location, illegal type, vehicle type, license plate color, license plate number, body color, etc. Three consecutive images can accurately and clearly reflect the process of vehicles breaking the red light illegally. Four images will be combined into an evidence image. At the same time, a set of illegal images has a high-definition video corresponding to it.

Monitoring and Recording Function for Driving in Noncompliant Lanes: The electronic police system uses direct video analysis to monitor the driving state of the vehicle, which can accurately judge the illegal behavior of the straight lane left/right turn, right-turn lane straight going or left-turn, left-turn lane straight going, or right-turn (as showed in Fig. 7.4). At the same time, a group of illegal pictures corresponds to a high-definition video.

Vehicle Retrograde Automatic Monitoring and Recording Function: The system uses video tracking technology to track each motor vehicle in the screen, which can directly detect vehicles driving in the reverse direction in the captured lane and directly identify the vehicles license plate information (as showed in Fig. 7.5). At the same time, a group of illegal pictures corresponds to a high-definition video.

Interval Speed Measurement and Recording Function: The system sets two adjacent monitoring points on the same road section, calculates the average driving

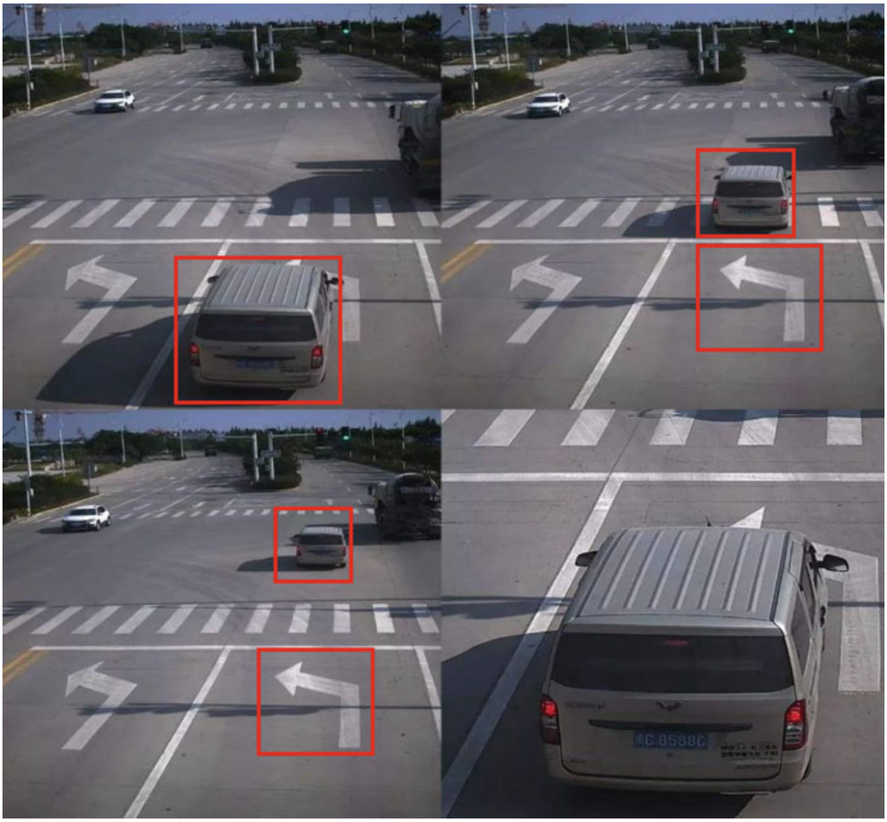


Fig. 7.4 Snapshot of vehicles driving in noncompliant lanes

speed of the vehicle on the road section based on the time of the vehicle passing through the two monitoring points before and after, and determines whether the vehicle is speeding or not according to the speed limit standard on the road section. At the same time, it publishes the information of traffic illegal vehicles in real time on the LED screen to inform and warn more vehicles (as showed in Fig. 7.6).

Monitoring and Recording Functions for Vehicles Occupying Lanes Illegally: Based on vehicle trajectory tracking and judgment, the system can detect and record the illegal driving and parking behaviors of vehicles in the monitoring area in bus lanes, nonmotorized lanes, emergency lanes, etc. The capture pictures include forbidden signs, lane lines, vehicle location, license plate, etc.

License Plate Number Automatic Identification Function: The system can locate and identify the license plate number automatically. Possessing license plate calculation automatic recognition ability of the civil vehicle, police vehicle, military vehicle, armed police vehicle license plate calculation automatic recognition ability.

Bayonet Recording Function: The system adopts video detection technology to detect, capture, record, save, and identify all vehicles passing through each lane at

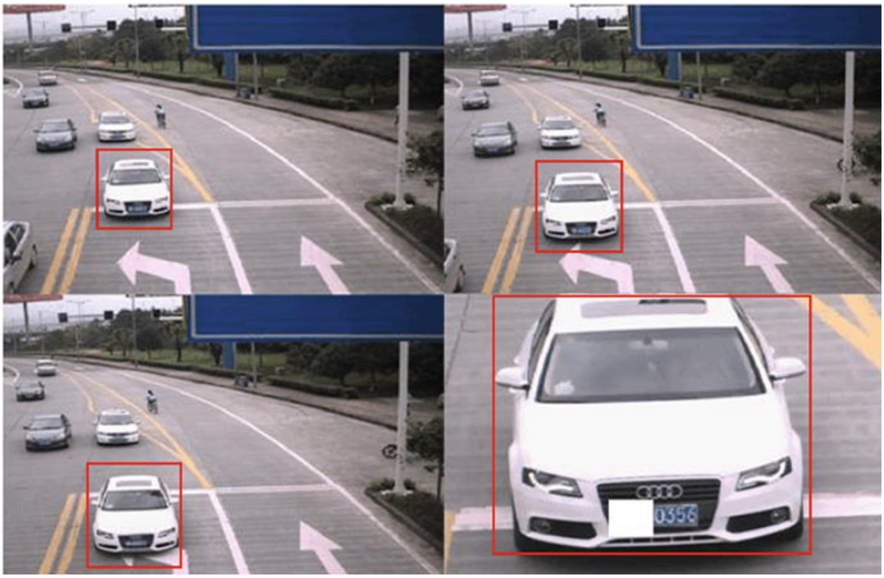


Fig. 7.5 Snapshot of retrograde vehicle

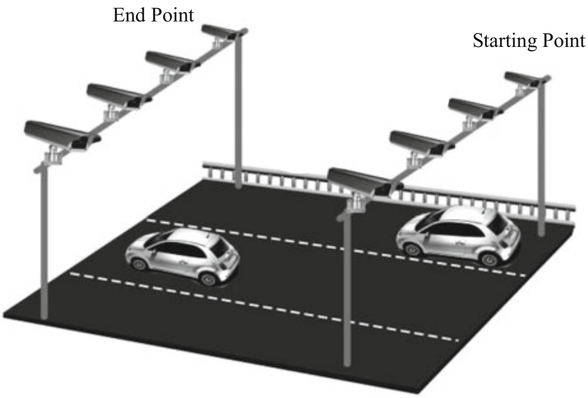


Fig. 7.6 Schematic diagram of interval speed measurement

red, green, and yellow lights, and identify license plate information. The bayonet image is a composite, the left half is a panoramic image of the vehicle, and the right half is a close-up image of the vehicle. All recorded vehicle passing information includes time, location, direction, vehicle type, vehicle license plate number, license plate color, etc.

7.2.2.3 Key Technologies for Electronic Police Systems

Cameras are installed at traffic intersections to take videos of the traffic intersections, and the task of automatic illegal recognition and automatic license plate recognition is completed by computer threshold comparison and analysis of digital image signal.

Automatic violation identification is to identify dynamic objects (such as vehicles), track their trajectory, and then automatically determine vehicle violation by relying on road signs and intersection signal lights in the monitoring area. The key links involved are as follows.

1. Detection of Moving Target: The main technical means used in this link include background image difference method, inter-frame different method, and optical flow method. These three methods each has their own characteristics, combined with different actual situation can achieve better application effect.
   (a) Background Image Difference Method: The basic principle is to first store the static background in the monitoring field of vision, and then subtract the real-time image from the static background in the actual operation. The value of each pixel of the difference is compared with the predetermined threshold. If the pixel value is greater than the threshold, it is considered to be the foreground point, otherwise it is the background point. When using this technical solution, it is greatly affected by external conditions such as light and weather, because in different weather and different light conditions, the background image is not static, so it is difficult to construct an ideal static background image as the basis. Another problem is to determine the predetermined threshold. Only the appropriate threshold can correctly segment the target area, which also needs to be adjusted and determined according to the actual situation.
   (b) Inter-frame Difference Method: This solution is to make a difference between a series of adjacent two frames in the recorded video image. The target contour is obtained by dividing the operation. In the recognition of multiple moving targets, this scheme can achieve good results. Since the interval time of the two images in the video is so short, so the change of the background is also little, and the influence on the difference is little. The disadvantage is that the differenced image is not composed of an ideally closed contour area, and the obtained target is often local and discontinuous, which is detrimental to the recognition of moving targets.
   (c) Optical Flow Method: The basic principle is to set a velocity vector for each pixel in the video to form a whole image motion field. At the fixed time of motion, the points on the image correspond to the points on the three-dimensional object one by one, and then the image is dynamically analyzed according to the velocity vector characteristics of each pixel. According to the optical flow vector of the image, continuous change of this area is analyzed to determine whether there is a moving target. Optical flow method avoids the selection of basic static background and threshold in differential time, but the

calculation of vector analysis for each pixel is large and vulnerable to video noise. The real-time processing of images cannot be achieved according to the existing hardware processing ability, and the application range is limited.

2. Multi-target Tracking: Segment the object in the video stream, then segment the object with the object of the previous image the tag is matched to achieve the purpose of tracking. The basic principle is to match the region in the current image frame and the target region of the known image. If the known target region is represented as a target list, all the regions in the current image frame are represented as a measurement list. For each element in the measurement list, the most similar element is found in the target list. This method is suitable for the case of small interaction between targets, and has a large relationship with the selection of target features.
3. Discrimiation of Vehicle Violations: After the vehicle trajectory is extracted, the vehicle violations are automatically identified according to the traffic light signals and road traffic sign lines. When dealing with traffic violations, three important evidence must be recorded: the violation screen, the panoramic position of the illegal vehicle, and clear license plate number. Among them, panoramic position of the illegal vehicle indicates that the vehicle was indeed in the illegal position, and a clear license plate number, which clearly identifies the violation vehicle. Therefore, only the video surveillance system based on computer technology can complete automatic monitoring. As an important part of the current intelligent transportation system, automatic vehicle recognition has gradually formed several mature and effective recognition technologies, such as radio frequency identification, license plate recognition, and bar code recognition. Barcode recognition and radio frequency recognition belong to indirect recognition, it is difficult to effectively identify whether the vehicle is true and consistent with its license plate information. License plate recognition is a direct recognition no corresponding barcodes or other radio frequency identification signs need to be installed in the vehicle, and it is easy to maintain and use. Automatic license plate recognition uses the vehicle picture taken by the camera as the input image, and uses computer image processing and pattern recognition technology to recognize license plate characters.

License plate recognition system has two triggering methods: one is peripheral triggering and the other is video triggering. The working mode of peripheral trigger means that the coil, infrared, or other detectors are used to detect the vehicle after receiving the vehicle trigger signal through the signal and license plate recognition system, and then the vehicle image is collected, the license plate is automatically identified and the subsequent processing is carried out. Video trigger means that the license plate recognition system uses dynamic moving target sequence image analysis and processing technology to detect the movement of vehicles on the lane in real time, capture the vehicle image when the vehicle passes, identify the license plate, and follow-up processing. Video trigger mode does not require coil, infrared, or other hardware vehicle detectors.

7.2.3 Intelligent Public Transport Management System

7.2.3.1 Overview of Intelligent Public Transport Management System

Intelligent public transport management system integrates modern communication, information, electronics, control, computer, network, GPS, GIS, and other technologies into the public transport system. Under the premise of key basic theoretical research such as public transport network distribution and public transportation dispatching, through the establishment of public transport intelligent transport dispatching system, geographic information system, public transport information service system, and public transportation electronic toll collection system, etc., make it more convenient for managers, operators and individual travelers to coordinate with each other and make clearer decisions. Through the construction and implementation of intelligent public transport system, the purpose of alleviating the pressure of public transport passenger flow, balancing the full load of public transport vehicles, reducing the cost of public transport operation, and improving the efficiency of travel, so as to establish a convenient, efficient, comfortable, environmentally friendly, and safe public transport operation system. The informatization, modernization, and intelligence of public transport dispatching, operation, and management will attract public transport, alleviate urban traffic congestion, and effectively solve urban traffic problems.

Intelligent public transport management system mainly takes travelers and public transport companies as the service objects. For travelers, the intelligent public transport management system collects and processes dynamic data (such as passenger flow, traffic flow, bus location, bus station waiting status, etc.) and static traffic information (such as traffic laws, moral management measures, location of large bus travel generation sites, etc.), and provides dynamic and static public traffic information (such as departure schedule, transfer route, optimal route guidance, etc.) for travelers through various media, so as to realize the purpose of planning travel, optimal route selection, avoiding traffic congestion, and saving travel time. For public transport enterprises, the intelligent public transport management system mainly realizes the dynamic monitoring, real-time dispatching, scientific management and other functions of public transport vehicles, and realizes the modernization and information management of public transport enterprises, so as to improve the service level of public transportation and the operating efficiency of public transport enterprises.

7.2.3.2 Composition and Function of Intelligent Public Transport Management System

For public transportation enterprises in domestic cities, the organic combination of the intelligent operation system of public transportation and intelligent management system of public transportation enterprises can fully realize the sharing and application of public transportation information resources. The aforementioned two systems share data and other related business operations through the bus communication subsystem and data center. The system architecture of urban intelligent public transport management system is shown in Fig. 7.7.

1. Intelligent Operation System of Public Transport

   The intelligent operation system of public transport is mainly composed of the following eight parts:

   (a) Data Center: The data center is the hub of information interaction between each subsystem of the urban intelligent traffic management system, which mainly completes the collection, storage, and processing functions of public transport–related information. The data center logically consists of a central database system, data processing system, and database management system. The central database system is responsible for the collection and storage of data, and the data processing system is responsible for the fusion and preliminary data processing of the data collected by the bus information collection subsystem.
   (b) Public Transport GIS Platform: The public transport GIS platform system uses information processing technology to establish the integration of vector electronic map database, relational database, and other multi-platform and multi-database based on public transport information. It has strong spatial analysis and spatial data processing ability of traffic network system, realizing the best route selection mode under the condition of the least number of transfer and shortest distance, etc., and has the query function of common passenger traffic information such as aviation, railway, waterway, and highway.
   (c) Public Transport Communication Subsystem: According to the data transmission requirements between subsystems, the bus communication subsystem can choose to use various wired communication modes such as optical fiber network, Ethernet, ADSL, MODEM, and wireless communication modes such as wireless conventional communication, wireless cluster communication, GSM, CDMA, and satellite communication.
   (d) Public Transport Information Collection Subsystem: The public transport information collection subsystem is a prerequisite for the normal operation of public transport dispatching subsystem, public transport information service subsystem, public transport evaluation subsystem, and other modules. The real-time dynamic information collected by the bus information collection subsystem provides the basis for bus enterprises to achieve real-time vehicle dispatching and provides basic data sources for bus information services. At the same time, the historical information of the central database of public transport management can also provide data support for long-term bus dispatching and bus system evaluation.
   (e) Public Transport Information Service Subsystem: Public transport information service subsystem is an effective way to improve the reliability of public transport travel modes, and it is also an effective means to guide the balanced distribution of traffic demand. A complete public transport information

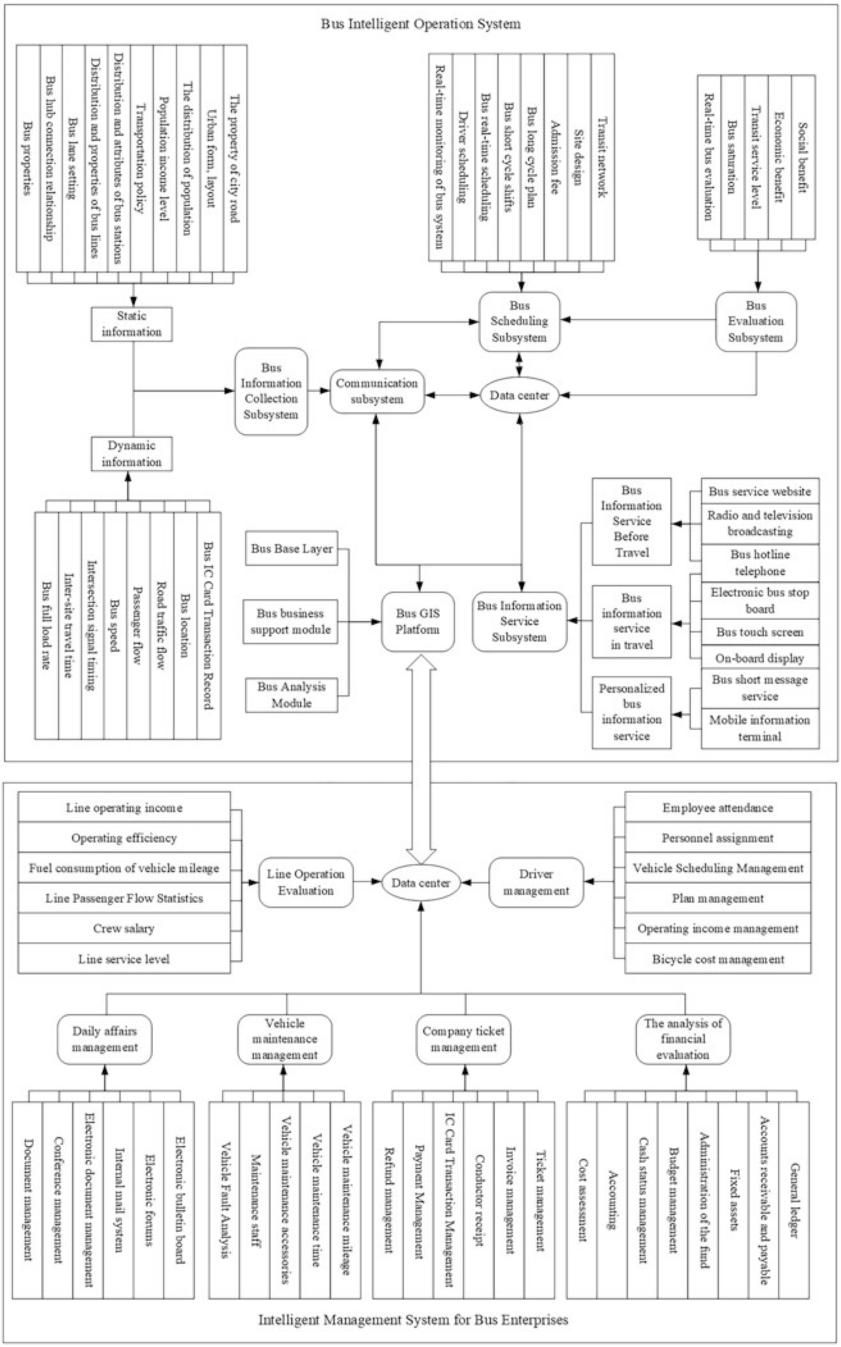


Fig. 7.7 Frame diagram of urban intelligent public transport management system [1]

service system can provide multifaceted information services for passengers, including pretravel information services, travel information services, personalized information services. At the same time, the public transport information service subsystem will provide public transport information services for other transport enterprises and relevant management departments and government departments through data interfaces.

(f) Public Transport Dispatching Subsystem: Public transport dispatching subsystem is the core subsystem of the whole intelligent urban public transport dispatching system. In terms of classification, it divides into line dispatching and regional dispatching. The bus dispatching subsystem includes four modules: intelligent public transport dispatching module, real-time public transport dispatching module, public transport dispatching optimization module, and intelligent public transport regional dispatching module. Among them, the intelligent public transport dispatching module will determine the dispatching of each route and the time when the public transport arrives at each station according to the passenger flow prediction of the line and the public transport real-time operation dispatching module in the process of bus operation according to the change of passenger carrying rate and public transport travel time prediction of each public transport real-time dispatching. Public transport is dispatching optimization module independently optimizes the real-time public transport dispatching module according to the historical data of public transport enterprise operation, urban planning, traffic management, and other aspects of information. The regional dispatching module integrates the management and dispatching of public transport lines in the region on the basis of intelligent dispatching of public transport lines, makes full use of the resources of public transport enterprises, and also improves the service level of public transport.

(g) Public Transport Evaluation Subsystem: The public transport evaluation subsystem mainly evaluates the operation of public transport enterprises according to the satisfaction index of the social system to the operational performance of public transport enterprises.

(h) Public Transport Tolling Subsystem: Public transport tolling subsystem introduces the IC card as a bill medium into the operation of public transport enterprises, which avoid the process of cash transactions and change for flight attendants.

2. Intelligent Management of Public Transport Enterprise

Intelligent management system of public transport enterprise is the management system of public transport enterprise itself. It is an intelligent information management system covering all relevant departments of the public transport enterprises, and provides information exchange with the central database system, including the functions of the MIS system and OA system. It mainly realizes the automatic management and paperless office of public transport enterprises, and its main functional modules include line operation evaluation, company ticket management, daily affairs management, vehicle maintenance management, fleet and bus station management, crew management, and financial evaluation and analysis.

7.2.3.3 Key Technologies of Intelligent Public Transport Management System

For the dispatching problem of public transportation, the commonly used methods include static dispatching and dynamic dispatching. Among them, static dispatching mainly refers to the departure time according to the prearranged timings. Dynamic dispatching includes vehicle dispatching, driver dispatching, and vehicle control and adjustment. Normalization of public transport operation can be realized by dynamic dispatching. It is difficult to respond to the actual situation in the operation of public transport vehicles by static dispatching. Because in the general public transport dispatching system, the travel and time of the vehicle are based on experience, without considering the actual operation of the unexpected situation. Therefore, during the process of vehicle design and operation, it is difficult to deal with various emergencies and ensure optimal dispatching only by static dispatching. When the actual situation changes, the flexibility of the static method is not good. Dynamic dispatching can reduce the waiting time of passengers and improve the level of public transport services through real-time dispatching of public transport.

This section lists a simple dynamic dispatching scheme. Considering that the actual situation of the vehicle in the operation process is very complex, in order to effectively simplify the research process, the following assumptions are made.

1. Human factors, road traffic, and other factors during the operation of vehicles are not considered, so that the operation time of different vehicles between the same adjacent stations is the same.
2. The parking time of a bus at each station is fixed, and is not affected by factors such as the number of passengers.

In the dynamic dispatching model, the various parameters are defined as following. Station set is $K \in \{K| K = 1, 2, \ldots, N\}$. The vehicle set is $I_m = \{i, i + 1, \ldots, i + m - 1\}$, and $i \leq m \leq M$. M represents the maximum number of vehicles that the bus system can provide, d_{ik} represents the time when the vehicle comes out, δrepresents the time when the vehicle enters and leaves the station in minutes. Therefore, if the vehicle can save the inbound and outbound time, you can reduce the operation time, $\delta = 0$, c_0 is used to indicate the parking time of the bus at the station, and the unit is also in minutes, the time that can be saved without parking is expressed as $\Delta = c_0 + 2\delta$.

To achieve dynamic dispatching, the fundamental problem is to determine the objective function, that is, to ensure that the time and minimum required for all passengers in the station while waiting for the vehicle. The model is defined as min (W). Assuming that the number of all passengers in a time period h_{ik} is $h_{ik}r_k$, the average waiting time for all passengers in that time period can be expressed as$h_{ik}/2$.

After derivation, the time cost required for passengers waiting for the ith car at station k can be set as:

$$w_{ik} = r_k h_{ik}^2/2 + h_{ik}P_{i-1k} \tag{7.1}$$

In the above formula, w_{ik} represents the time cost of passengers waiting for the ith car at k station. r_k represents the passenger arrival rate of a bus station. P_{i-1k} represents the number of remaining passengers of ith vehicle at station k. In the absence of dynamic dispatching, $P_{i-1k} = 0$. h_{ik} represents the departure time interval between vehicle i and vehicle $i - 1$ at station k. h_i represents the time interval between vehicle i and vehicle $i - 1$ at any station. Therefore, according to this definition, $h_{ik} = d_{ik} - d_{i-1k}$. Therefore, the waiting time cost of passengers at each site of the line can be converted to:

$$W = \sum_{i=1}^{m} \sum_{k=1}^{K_C} \left(r_k h_{ik}^2/2 + P_{i-1k}h_{ik} \right) \tag{7.2}$$

From Eq. (7.2), the waiting time cost of passengers can be calculated, and the dynamic dispatching model can be further constructed. That is, the dynamic dispatching is carried out between the vehicle i and the vehicle $i - 1$. If the number of stations that the two vehicles do not stop during the operation is assumed to be n_1 and n_2, the time saved by the two vehicles through non-stopping can be expressed as $n_1\Delta$ and $n_2\Delta$. In general, in order to reduce the waiting time of passengers at non-stop stations and promote the uniformity of the vehicle interval on the entire line, $n_1 \geq n_2$ should be set. As shown (Fig. 7.8), the dotted line represents the departure time without dispatching, while the solid line represents the departure time after dynamic dispatching. The mainly vehicles that can affect passengers waiting time cost are i, $i + 1$, $i + 2$. If w_1, w_2, w_3 are used to represent the waiting time cost of stations and 0~n_2, n_2~n_1 and n_1~N refer to the difference of waiting time cost

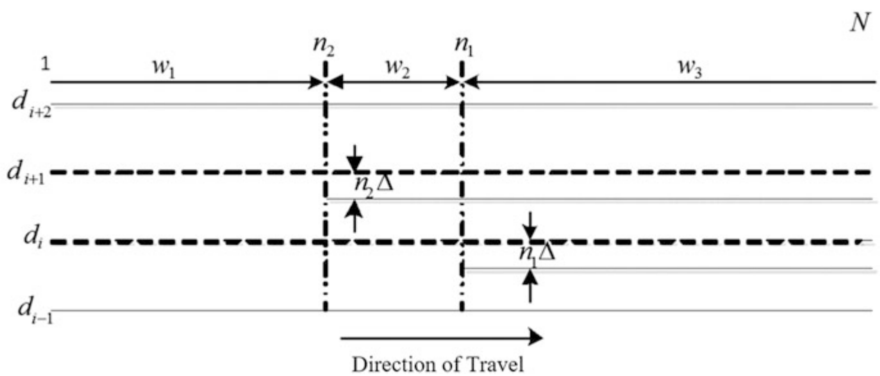


Fig. 7.8 Dynamic Dispatching Model Diagram of Bus

without parking, respectively. Thus, the entire waiting cost can be expressed as $w = w_1 + w_2 + w_3$.

7.2.4 Parking Guidance Information System

7.2.4.1 Overview of Parking Guidance Information System

Parking Guidance Information System (PGIS) includes large parking intelligent guidance system and urban parking guidance system. It is a system that uses multilevel information release as the carrier to provide real-time information such as the location of the parking lot (garage) location, the number of parking spaces, and the state of empty space, so as to guide the driver to park. It plays an important role in regulating the uneven distribution of parking demand in time and space, improving the utilization rate of parking facilities, reducing the road traffic caused by looking for the parking lot, reducing the waiting time caused by parking, improving the efficiency of the entire transportation system, improving the operating conditions of the parking lot, and increasing the economic vitality of the commercial area.

7.2.4.2 Composition and Functions of Parking Guidance Information System

The general PGIS consists of four subsystems, namely the information collection subsystem, the information release subsystem, the information processing subsystem, and the information transmission subsystem. The overall function of PGIS in big cities is to release parking information and provide basic data for urban intelligent transportation systems. The direct function of PGIS is to provide parking information to traffic managers who have parking needs.

The overall structure of PGIS adopts centralized-distributed system architecture. The collection and processing of data information and the layout of the database are distributed, and the sharing and fusion of data and the maintenance and management of consistency are centralized.

1. Information Collection. The information collection of PGIS is an important part. It is also the basic work of parking lot design, road infrastructure construction and even traffic planning. Through the collection of information such as the number, location and utilization status of parking spaces, it can not only provide information guarantee for the release of PGIS, but also grasp the status and laws of parking, clarify the nature of parking problems, and propose targeted solutions.

   Information Collection Classification: The information collection of PGIS can be divided into static data collection and dynamic data collection. Static data collection is a stable and constant information in the PGIS for a period of time. It mainly completes the statistics and input of the location, type, and rate of each parking lot or roadside parking space, as well as the information of related stations with parking-transfer functions. Dynamic data collection is information about the relative changes in time, such as the utilization of parking spaces and the opening and closing of parking lots. According to data sources, parking information collection can be divided into direct collection and indirect collection. Direct collection through the parking management host to obtain parking information, and indirect collection through other intelligent transportation system each collection data node integration of traffic industry information.

Principle of Data Collection. Data collection can be divided into the following three categories:

(a) Manual Collection: Manual collection is a relatively traditional nonautomatic collection, which does not require complex equipment, but the accuracy and timeliness of information is difficult to control.
(b) Collect According to Vehicle Characteristics: Traffic information collection is mainly to detect vehicles, and convert the existence and movement of vehicles into electrical signals output. The vehicle is a component that contains a lot of iron. An entity with quality and geometric shapes, and has certain characteristics of light, heat, and electricity. According to these characteristics, information collection includes methods such as magnetic detection, ultrasonic detection, electromagnetic wave detection, thermal detection, quality detection, and video image detection.
(c) Collect with the Help of External Objects: With the development of transportation, the PGIS has higher requirements for information, not only the number of vehicles, but also the distinction of different collection objects, and then different strategies are adopted. The more common ones are number identification and IC card.

2. Information Processing: The information processing of parking guidance system not only provides parking information, but also undertakes the tasks of storing parking information or roadside parking information and processing the change mode of parking usage. These functions will lay the foundation for future parking demand forecasting and parking reservation. The parking information processing of parking guidance system is realized by management software in two steps, namely front-end processing system and management center system.

   The front-end processing system generally refers to the parking management system, which mainly has the following functions.

   (a) Import and export data of vehicles are collected, such as vehicle properties, vehicle number, import and export time.
   (b) Utilization of parking space.
   (c) Other functions required by parking management, such as charging statistics.

The functional composition of the management center system is shown in Fig. 7.9.

Change of Parking Space during Travel Time: From the current collection technology, the parking space collector for the current parking space collection is relatively clear, but it cannot make an accurate prediction for the future parking

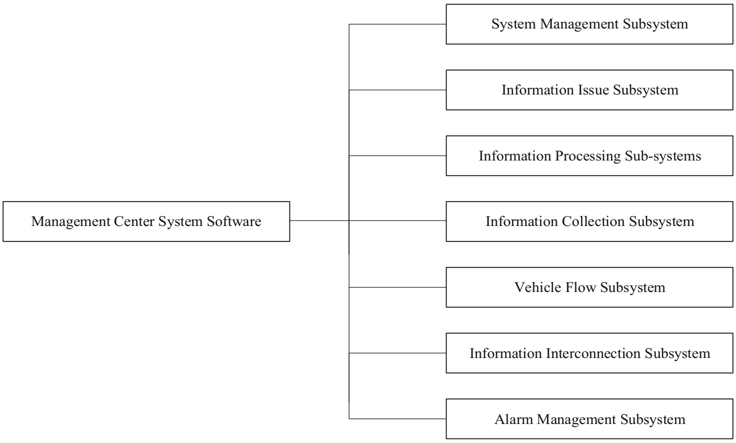


Fig. 7.9 Function composition of management center system

space changes. In order to prevent the driver from seeing the information in the parking lot with a certain distance between the screen and the parking lot, it is necessary to process the information in the parking lot with a reasonable distance.

System Optimization: In the regional PGIS, the system always considers how to provide parking information to drivers accurately and timely. Although this model is simple and practical, there are also some shortcomings, such as the limited information provided, unable to consider the different requirements of different drivers, that is, unable to achieve the interaction between the system and users. With the establishment of urban intelligent transportation information platform, traffic flow guidance system, GPS, and multi-level PGIS, the information processing of PGIS has higher requirements. The system optimization of PGIS is to draw up a reasonable traffic control strategy, that is, the optimal model of the system, based on the parking management and smooth traffic flow of the whole city, and then take corresponding countermeasures according to different system objectives.

Information Release: Parking information release is the main part of PGIS, which can be divided into fixed guidance information and variable guidance information according to whether the guidance information is variable. The fixed guidance information is mainly based on parking signs. Because of its low cost, it can be used as a useful supplement for the guidance information release of parking lots. The variable guidance information release plate can provide the changing parking space or parking lot information, and some fixed guidance information is attached to the variable information release plate, which can save the cost or improve the stability of the release system.

Information Forms: Common parking guidance screen information are shown in Table 7.1.

Guidance Information Classification Requirements: The induction system should be designed into a three-level or four-level induction system according to the

Table 7.1 Common information forms of parking guidance screen

Level	Types of signs	Static content	Dynamic content
A	Text + arrow	P vacancy + induced region name + arrow	Total regional remaining berths
B	Map	P vacancy + road network	Total number of remaining berths
C	Text + arrow (combined type)	P vacancy + parking name + arrow	Total number of remaining parking lots
D	Text	P vacancy + parking name	Total number of remaining parking lots

Table 7.2 Classification system of parking guidance system

Property	Level	Effect	Proposed location
Regional level predictability induction markers	Level 1(A)	Display the location and control information of the induced area	Regional peripheral main road
	Level 1(B)	Zone induction, guiding the location and vacancy letter of adjacent zones	Main roads outside the subregion
Street level induction signs	Level 2(C)	A sign indicating the parking lot along the road information	Intraregional roads
Parking level indicator sign	Level 3 (D)	Guide the parking location and total blank information	Parking entrance

characteristics of the induction region. Generally, the use of level 3 inducers are as shown in Table 7.2.

The district that publishes the regional parking space information. In the multilevel PGIS, information release often involves statistics and processing of regional space data. In view of the cross-regional nature of information release, in order to improve the guidance effect, in the sub-management center, the distribution of regional information is distributed and the physical area is processed. The division of information collection should be different. The partitions for releasing regional parking space information mainly go along the following principles: The range of each partition should not be too large, it should be limited to 6–8 blocks, and it is best to control within a rectangular area with a side length of about 500 m; the name can be distinguished and easy to identify; the capacity of the parking lot in each zone is roughly equal to the parking demand; the road with heavy pedestrian traffic should be avoided to cross the zone; the induction route to the parking lot should be avoided as far as possible to make a left turn; each zone is best It can be separated by arterial road.

3. Information Transmission

   Classification of Communication: Transportation communications technologies include radio broadcasting, cable communications, microwave communications, mobile communications, optical fibers communications, digital baseband communications, digital carrier communications, infrared and ultrasonic communications, and satellite communications. Different communications technologies are applied in different scopes. The above communication technologies in ITS do not all exist independently, and most of them are mutual penetration and cross each other.

According to the management level of sender and receiver, the information transmission of parking guidance system can be divided into the following:

(a) Parking lot or roadside parking space—center of control.
(b) Management center—LED publishing screen.
(c) Management center—other information release methods.

4. Communications structure.

According to different transmission tasks, the communication of the parking guidance system can adopt different methods. At present, the more common wired optical cables, optical fibers, and wireless methods. Cables include solid wires, DPN data networks, etc., and wireless include GPS, GPRS, CDMA, etc.

7.2.5 Emergency Management System

7.2.5.1 Overview of Emergency Management System

Emergency management system for emergencies is a human-oriented; guided by scientific management theory; and on the basis of a scientific management system, it uses computer hardware, software, and network communication equipment to monitor and control the operating conditions of the freeway around the clock. Quickly detect and judge emergencies, and quickly take appropriate incident response measures to avoid traffic accidents (or secondary accidents) and ensure timely rescue and accident elimination after the accident, and support the drivers and passengers, integrated human–machine system for traffic vehicles and grassroots operations. The general goal of traffic emergency management is to take preventive measures before traffic accidents to reduce and avoid the occurrence of abnormal traffic accidents. When traffic incidents occur, timely discover and take appropriate emergency rescue measures to minimize casualties and property losses. And to minimize the impact of traffic delays caused by the incident, and return to normal traffic conditions in the shortest time.

7.2.5.2 Composition and Function of Emergency Management System

Emergency management is an important part of traffic safety management, which can significantly improve traffic safety and operational efficiency. Traffic safety emergency management is a systematic work, which includes emergency warning, emergency detection, emergency analysis, emergency decision-making, rescue execution system, emergency assessment, plan management, etc. Each link is related to

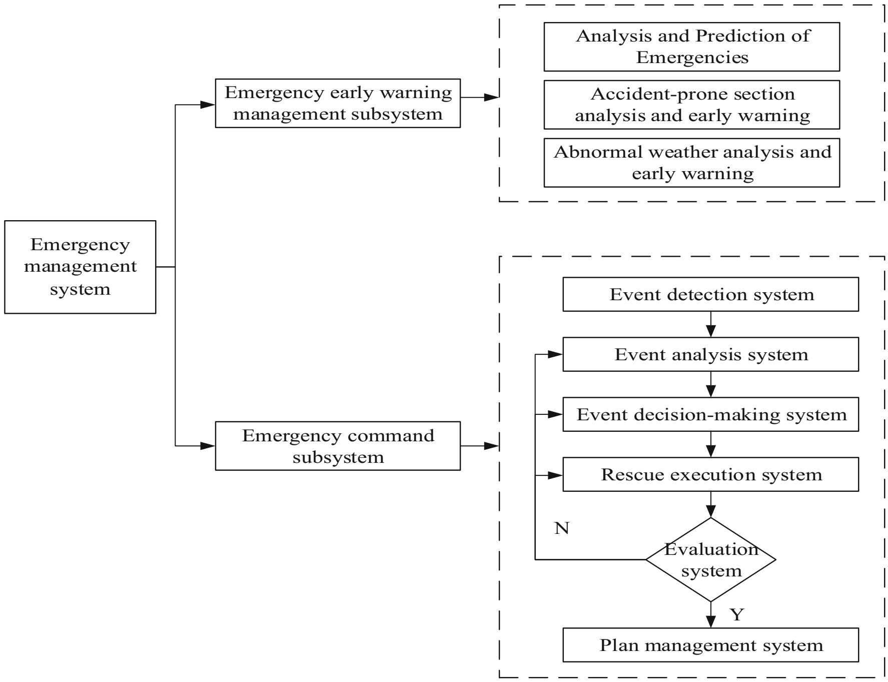


Fig. 7.10 Overall framework of emergency management

the efficiency and effectiveness of emergency management. The overall framework of emergency management is shown in Fig. 7.10.

1. Emergency Early Warning Management Subsystem. The main functions of the emergency early warning management subsystem include data mining, information collection, statistics and analysis of real-time traffic conditions and real environment, and find out the distribution characteristics of traffic accidents and their causes and influencing factors, such as traffic safety control in severe weather and risk factors in traffic accident-prone areas. The early warning system should immediately monitor these risk factors, issue early warning to the traffic safety management department, and take early warning programs in time to prevent accidents to the greatest extent. Emergency early warning management subsystem has three functional modules: traffic information processing and prediction module, accident-prone section analysis and early warning module, abnormal weather analysis and early warning module. According to the objective process of road operation activities, the working mode of emergency warning management subsystem is shown in Figure 7.11.

   The development of the road early warning emergency management subsystem is based on the operating company's monitoring of the traffic operation indicators of the roads under its jurisdiction. According to the obtained

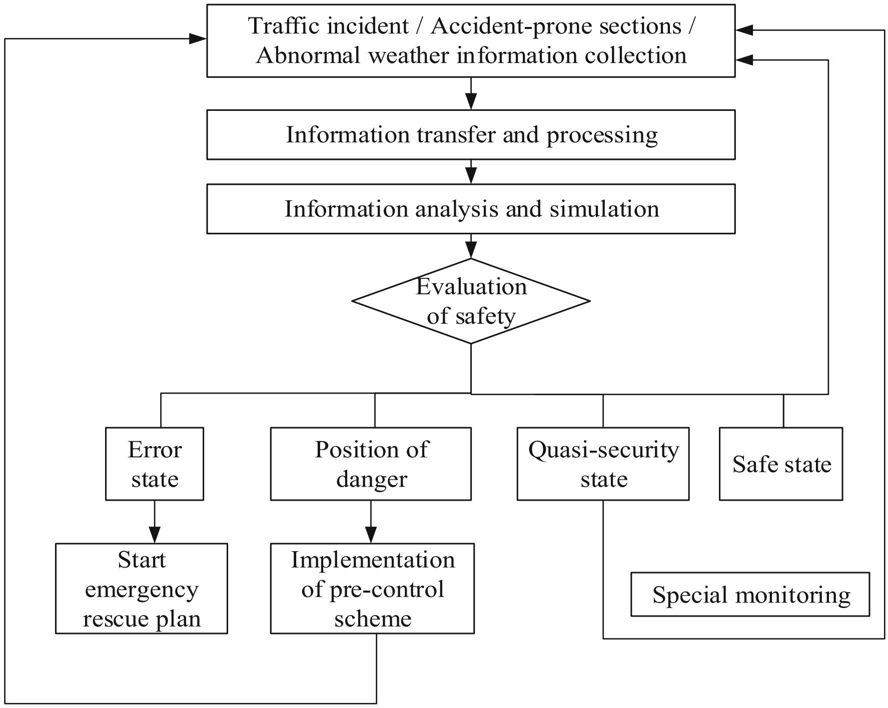


Fig. 7.11 Emergency warning management subsystem working mode diagram

information, the management department confirms that the monitoring indicators are in abnormal, dangerous, quasi-safe, or safe state by identifying, diagnosing, and evaluating the traffic phenomena and implements corresponding control countermeasures. When the indicator is in a safe state, continue daily monitoring. When the monitoring indicators are in a quasi-safe or dangerous state, the early warning department enters the special monitoring stage according to the specific situation or instructions, or proposes pre-control measures and is executed by the decision-making or the dispatching department until it is restored to a safe state, while the dispatching department enters the response plan into the response library for future reference. When the monitoring index enters the abnormal state, the entire road management organization enters the emergency rescue procedure, and starts the emergency plan until the road operation enters a safe state again.

2. Emergency Command Subsystem

Incident Detection System: Whether urban traffic emergencies can be detected in time is the first problem to be solved in traffic emergency management. The incident detection subsystem is used to detect and determine the nature of the incident. It integrates various detection and monitoring equipment (such as induction coil, video monitoring equipment, microwave detection equipment, floating car information collection equipment), and coordinates with relevant information departments to collect relevant meteorological, road environment, traffic flow conditions (traffic flow, velocity, interval travel time) and other information, timely predict, discover and analyze the location, scale and development trend of emergencies, and provide reliable basis for emergency response decision-making and command. Incident detection technology is the theoretical basis of event detection subsystem, which is not only related to whether the role of monitoring system (hardware part) can be fully played, but also has great significance for the treatment of accidents. For example, the rapid detection after the accident, the rapid response to the accident, taking appropriate traffic control measures to prevent the occurrence of secondary accidents, rapid processing of accidents, reducing accident losses, etc., all have a direct relationship with the incident detection algorithm.

Incident Analysis Subsystem: After the incident detection subsystem detects the occurrence and upcoming traffic emergencies, the original incident information, environmental information, and traffic information of the incident location are summarized into the incident analysis subsystem for further filtering and analysis. Within the incident analysis subsystem, it is necessary to complete the identification of the type, severity, cause and other factors of the event, and to determine the degree of decline in the capacity of the bottleneck caused by the incident, the possible blockage, and the degree of spread of the blockage. Perform analysis and prediction. Provide a basic basis for the next incident decision. The process of incident analysis is the process of incident confirmation first, because there will be a certain false alarm rate during the incident detection process, and the attribute data of the incident provided by the incident detection may be incomplete. Therefore, the incident analysis first needs to determine whether the incident is present or not. Make judgments, and then need to use various predesigned models and plans and special mathematical algorithms to classify and analyze the incident, and finally get the incident's characteristic information, severity, impact index, and other important parameters. When the data provided by the detection subsystem is not complete or incomplete, it is necessary to use data mining technology and data fusion technology to further process the attribute data of the incident.

Incident Decision-Making Subsystem: Decision analysis is the difficulty of traffic emergency management. It is responsible for generating rescue plans and notifying relevant departments to dispatch rescue resources. The module uses the information collected by the event detection subsystem and the preliminary results of the analysis subsystem to generate rescue strategies, including lane control strategy and ramp control strategy. The generation of these strategies should consider the traffic capacity of the relevant road network, the matching between the traffic capacity of each section, and the predicted driving time of each section. At the same time, the relevant rescue departments should be informed to implement the accident rescue process. The plan content generated by the incident decision-making subsystem should include the composition and responsibilities of emergency agencies, emergency communications support, organization of rescue personnel and preparation of funds and materials, preparation of emergency and rescue equipment, disaster assessment preparation, several parts of the emergency action plan. On the basis of the plan, the departments needed to be called for incident rescue should be designated, the responsibilities and permissions of each department should be clarified, the equipment needed for emergency rescue (medical equipment, fire equipment, vehicle traction hoisting equipment, etc.) should be determined, the specific steps for rescue implementation should be formulated, the emergency traffic control scheme should be put forward, the green channel for rescue vehicles should be formed, and the strategy of traffic guidance should be put forward. After receiving the emergency information report of the information system, the types and severity of emergencies are analyzed through the resource database and expert assistant decision-making system, and then the corresponding emergency treatment plan is launched for rescue, which provides the best route to the location of the incident for the relevant departments, and the emergency rescue instructions are issued through the communication system. In the emergency scene, according to remote-sensing images, video images and feedback information, emergency rescue measures are responded and adjusted at any time. According to different rescue needs and the division of labor of various functional departments, the relevant departments are informed of accidents and rescue needs information, and the rescue work is coordinated.

Rescue Execution Subsystem: The rescue execution subsystem is to coordinate various rescue departments (traffic police, hospitals, fire, road maintenance departments, armed police, military, etc.) after receiving emergency notifications, according to the plan division of the decision-making system, and perform their own duties to deal with emergencies and organize rescue, the traffic command department implements necessary traffic control on the scene, according to the rescue green channel and traffic guidance provided by the decision-making system, assist other departments to implement emergency rescue at the fastest speed, and eliminate emergencies in the shortest time. It also feeds back the situation of the incident site and the changes in the needs of various rescue departments to the incident decision-making subsystem in time, so that the emergency system can modify the emergency rescue plan in time, better implement the emergency rescue work, and make the road network traffic return to normal faster.

Effect Evaluation Subsystem: The main function of the evaluation subsystem is to evaluate the effect of solving traffic emergencies. Through the implementation of the rescue execution process, the traffic emergencies are either solved in time, or have not been effectively solved, or have not played the effect of reducing the loss of events. These need to be evaluated by the evaluation subsystem. The content of the evaluation includes the evaluation of the event itself and the evaluation of the traffic condition of the incident section. If the effect does not meet the requirements, the specific information that does not meet the requirements is fed back to the corresponding subsystem (including the incident analysis subsystem, the incident decision subsystem and the rescue execution subsystem) for reanalysis, decision-making, and rescue. If the evaluation results meet the requirements, the case of this traffic emergency is closed, and the relevant information of the whole event (including the time, location, type, severity, emergency plan, duration, emergency resources consumed, and emergency effect) is input into the plan management subsystem of urban traffic emergency to form a historical case database, which provides a useful reference for future traffic emergency management.

Plan Management Subsystem: The plan management subsystem is the intelligent warehouse of urban traffic emergency management system, which includes the model base, knowledge base, and historical database of traffic emergency management. These databases have practical and effective reference value for the management of emergencies. Establishing and improving the plan management subsystem of traffic emergencies is of great significance for traffic emergency management. Of course, the ideal database is not built at the beginning, needs to be gradually improved, and perfected in the daily incident management process. The plan management subsystem is mainly responsible for the collation and archiving of the basic information of emergencies and the whole rescue process information. It analyzes the causes of emergencies, evaluates the rescue effect, generates rescue reports, and provides historical basis for future event management.

7.2.6 Typical Urban Intelligent Traffic Management System and Its Application

7.2.6.1 Intelligent Traffic Management System of Beijing

In recent years, Beijing has constructed an ITSM framework with “one center, three platforms and eight systems” as the core, which is highly integrates nearly 100 application subsystems such as video surveillance, individual positioning, 122 alarm and command, GPS police vehicle positioning, signal control, cluster communication, and strengthens the practical ability of intelligent traffic management. The structure of ITMS of Beijing is shown in Fig. 7.12.

1. Upgrade and Transformation System of Traffic Operation Monitoring and Intelligent Analysis Platform: The upgrade and transformation system of the transportation operation monitoring and intelligent analysis platform is considering the needs of transportation decision-making, and fully integrates real-time dynamic traffic flow data, public transportation operation data, industry statistics data, travel characteristic data, infrastructure data, transportation geographic information data, and urban background data to build a traffic decision database. The intelligent analysis platform is mainly based on the private cloud platform of the core calculation engine of Hadoop road network operation monitoring traffic operation evaluation and decision analysis system. It realizes special analysis of urban road network operation monitoring, public transport operation monitoring,

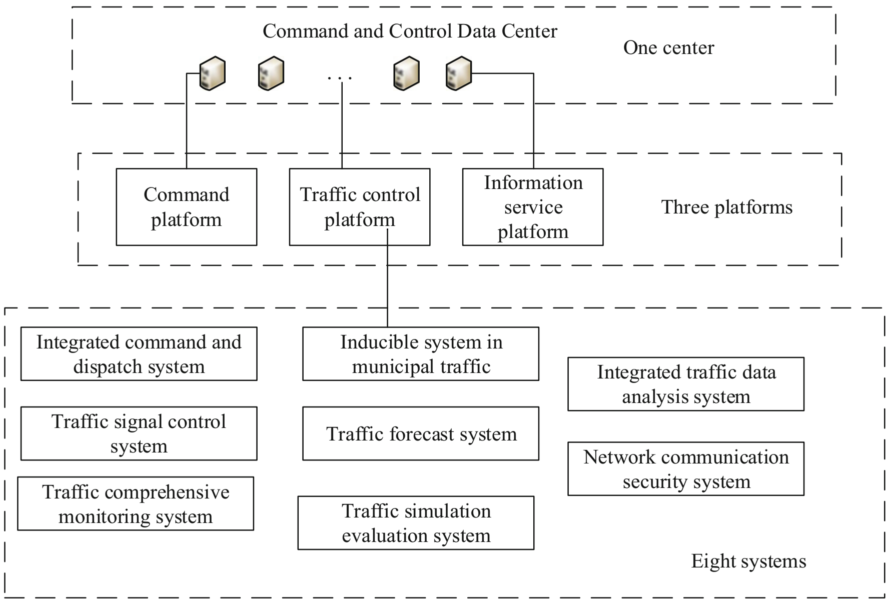


Fig. 7.12 ITMS of Beijing

and highway operation monitoring analysis, and establishes the traffic operation monitoring and intelligent analysis platform upgrading and transformation system that meets the stability requirements of TB data level and industrial application system.

2. Wireless Geomagnetic Vehicle Detection System: The wireless geomagnetic vehicle detection system (MVDS) uses fully automatic adaptive geomagnetic detection technology. By laying wireless magnetic induction intensity sensors on the road, it can perceive the change of spatial magnetic field when the vehicle passes through. It has the advantages of standard adaptive tracking and high recognition rate. In 2016, led by the Beijing Transportation Commission, the thirty-eighth Institute of China Electronic Technology Group and the Highway Research Institute of the Ministry of Transportation carried out the technical verification test of parking monitoring equipment. The wireless geomagnetic monitoring system has outstanding performance in accuracy, stability, and durability. It has passed the test contents such as emission spectrum, magnetic field sensitivity, waterproof and dustproof, high and low temperature and humidity, anti-interference, etc. Finally, the comprehensive accuracy of 91.4% is obtained and passed the test smoothly.
3. Video Surveillance System for Public Transport Vehicles: The video surveillance system for public buses has achieved full coverage of 1087 public buses. It is planned to complete the 3G/4G wireless dedicated line network access of 1087 buses on the existing basis, and complete the construction of supporting projects such as the company's image management center computer room and other

facilities and network expansion in 2018. Based on the original image information management system center and seven subcenters, a public transport vehicle video monitoring and management platform is constructed, which includes the upgrading of the image management center platform, and the increase of video control, management, and alarm functions. On the basis of integrating image resources, improve the image information sharing system with the Municipal Transportation Committee, the Municipal Public Security Bureau's Bus Corps, and the Municipal Public Security Transportation Administration to realize the effective sharing and utilization of image information resources.

4. Intelligent Operation Dispatching System for Public Transport Vehicles: In 2016, on the basis of the original function of intelligent dispatching system, the bus group company upgraded and improved the dispatching system, and completed the docking of important basic data such as people, vehicles, and lines of the dispatching system with the group information resource management platform. Besides, it finished the localization of dispatching system, line access of multiple operation modes and optimization of real-time computing module. The optimization of the report system realizes the unification and standardization of the basic data sources, the support of the dispatching system for the state without network, and the compatibility of the departure mode of all the registered lines in the group. It strengthens the usability and adaptability of the dispatching system, and the statistical data of the system is timelier and more reliable.
5. Image Management Platform of Public Transport Group: The image management platform of public transport group has built a security monitoring system of 1 center, 7 sub-centers, 16,000 vehicles, 215 midway stations, more than 100 bus stations, and 390 bus stations and 757 midway stations are under construction. It strives to realize the full coverage of bus and bus station monitoring system and the full coverage of bus midway station monitoring system in key areas, to realize the all-round, all-weather, and three-dimensional control of the ground bus system, and to realize the image and video docking with the transport administration, traffic administration and public security, so as to improve the overall level of public security order in the field of public transport. Since the establishment of public transport image system, more than 1000 videos have been collected for public security organs every year, which plays an important role in building a "Safe Beijing."
6. Customized Public Transport E-Commerce Platform: Beijing Public Transport Group launched a customized bus platform. Passengers in Beijing can participate in travel demand survey through the customized public transport platform, and book business public transport seats and online payment through the customized public transport platform. Completed custom public transport IC card identification system development and more than 130 business bus on-board equipment installation work, through the card to complete authentication. Complete the development of large customer group purchase, spare seat reservation, passenger automatic distribution, and other functions, which laid the foundation for business expansion. The development and online of commercial vehicle charter channel are completed. Customized bus mobile app officially launched,

passengers can be communicated and collected through the phone from line browsing, order submission to mobile payment process operation, etc. Customized public transport APP and WeChat also have the functions of passenger self-checking tickets, free ticket issuance and transfer, arrival forecast of fast direct line module and passenger circle.

7. Public Transport Route Inquiry Service App: "Public transport online" is a free real-time public transport information query app based on smart phones released by Beijing Public Transport Group. The public transport online APP realizes the real-time arrival broadcast of all public transport routes. At present, the download has reached 410,000 times. The arrival forecast function, after selecting a certain station on a certain line, you can query the distance from the nearest three vehicles to the station and the expected arrival time.

   Line customization function: Common lines can be customized, and the forecast information of the station on the line after customization will be displayed on the front page of APP, which is convenient and quick.

   The arrival reminder function: Set the line arrival alarm clock, when the vehicle arrives at a station a few minutes before reminding passengers to go out in advance.

   Transfer query module can query white/night public transport transfer information, and passengers can directly view real-time bus information in the transfer interface, more convenient to use. The user center module includes feedback, public transport news query, offline map download, version query, and other functions. In addition, the APP can be shared to more people through WeChat, circle of friends, QQ Zone, microblog QQ, and other ways.

8. Beijing Traffic Police Mobile App: With the help of Internet + technology, the mobile phone app of Beijing traffic police has built a comprehensive platform for traffic management information service, business office, and police–civilian interaction. It has opened 15 major functions, such as accident handling, entering Beijing for licenses, and illegal collection. By the end of the year, 3.8 million registered users, 230 million visits, and more than 300,000 daily business transactions have been registered. It ranks first in the same kind of mobile phone government software in the country, realizing more data and less running leg for the masses. It not only facilitates the handling of the masses, alleviates the window pressure and road congestion, but also provides data support for further improving traffic management services.

9. Online Passenger Flow Analysis and Decision Support Platform for Urban Rail Transit. Beijing Transportation Industry Data Center and Beijing Transportation Information Center have developed an online passenger flow analysis and decision support platform for urban rail transit based on the application demonstration project of the Internet of Things for rail transit safety and prevention of Beijing Transportation Committee. The platform is the first domestic rail transit integrated big data processing and application platform that integrates government industry supervision, enterprise operation and auxiliary decision-making and public travel information service. It covers eight functions of rail transit basic information management, online passenger flow prediction, four-layer

congestion information release based on station, interval, line and road network, new line access passenger flow prediction, emergency passenger flow prediction, train operation plan evaluation, passenger flow statistics and analysis and emergency disposal. The platform has the models and algorithms of historical passenger flow sorting, real-time passenger flow prediction, new line access passenger flow prediction, and rail transit passenger flow simulation with independent intellectual property rights, and is the first, leading and suitable rail transit passenger flow analysis and decision-making platform in China. Based on the B/S architecture, this platform uses ROLAP, MOLAP, HOLAP and other branch processing technologies to optimize the database management and application, and forms an efficient, fast, and low resource consumption rail transit passenger flow big data solution. The platform provides strong decision support for rail transit operation monitoring, operation management, emergency management and information services, and is an important means to realize the leap of rail transit from network construction to network operation. The comprehensive promotion of the platform in China has important guiding significance for the realization of rail transit network operation in various cities.

7.2.6.2 Intelligent Traffic Management System of Shenzhen

Shenzhen has built an ITMS that including "one platform, eight systems." One platform is traffic information sharing platform, eight systems include traffic information collection system, traffic control system, grid vehicle identification integrated application system, arterial traffic guidance system, parking guidance system, traffic incident system, intelligent traffic violation management system, closed-circuit television monitoring system, etc. Among them, traffic information collection includes traffic control system, grid vehicle identification integrated application system, intelligent traffic violation management system, CCTV monitoring system, traffic incident system, etc. Traffic information integrated platform includes common information platform. Applications and services include arterial traffic guidance system, parking guidance system, intelligent traffic control system, etc.

1. Intelligent Traffic Control System: Intelligent traffic control system is the core system of ITS, which plays an important role in ITS system and is the main data source of platform and other systems. At present, there are 1308 signal intersections in the city, including 828 intelligent traffic signal control network intersections and 707 coil detectors. 46 adaptive control intersections can be realized. Shenzhen intelligent traffic signal control system is a distributed adaptive control system. Signal phase timing can be automatically carried out according to traffic flow. The classification of system function modules is clear, and the classification of system function modules is clear. Shenzhen intelligent traffic signal control system is in a leading position in China, and it can realize multi-period coordination control and dynamic optimization coordination control. The traffic management department of Shenzhen takes the lead in breaking through the technical threshold of countdown time. According to the change of traffic signal control

each cycle, the correct cycle and green light release time are calculated in advance, which solves the related technical problems of traditional countdown time. This technology is the first in the country, and its scientific and technological content is in the forefront of the country. It has high real-time and integrity, and it is shown in different directions according to the new national standard. It combines the intelligent pedestrian countdown with the motor vehicle countdown, which fully reflects the humanized management.

2. Grid Vehicle Identification Integrated Application System: Grid vehicle recognition integrated application project is a comprehensive information application system based on real-time monitoring and data collection of vehicle license recognition information. It provides vehicle information related application services for multiple units or departments, including public security traffic police, public security command, public security criminal investigation, public security technical investigation, municipal grid office, environmental protection bureau, land planning bureau, transportation bureau, etc. It realizes the monitoring, analysis, and prediction of road traffic state, the monitoring, management, and early warning of specific vehicles, the real-time calculation of various traffic violations, and the comprehensive analysis of vehicle information. Up to now, a total of 118 monitoring sections of the construction monitoring points have been completed, and the grid has been initially formed. Its scope basically covers the main roads in the city, as well as the second and the third line gateways in the city. It has realized the traffic illegal monitoring functions such as overspeed, off-road driving, fake license plate vehicles, yellow mark vehicles, single and double license plate limit. As well as the blacklist warning control, vehicle monitoring, and other social security functions, has achieved great economic and social benefits.
3. Traffic Incident Detection System: Traffic incident detection system is a part of traffic information collection and a high-level data detection system. The system will obtain the processed basic data and combine with manual detection to achieve timely warning of traffic incidents. The event detection system transmits the relevant information to the comprehensive control system, and then the comprehensive control system is released to the guidance system, command system and other related systems, which provides information guarantee for the rapid positioning, rapid alarm, and rapid evacuation of traffic events.
4. Arterial Traffic Guidance System: As a part of Shenzhen's traffic guidance system, the arterial traffic guidance system generates guidance information according to the guidance strategy and publishes it in time by using the collected real-time traffic information, so as to effectively guide the travel vehicles, improve the utilization rate of existing roads, realize the balanced distribution of traffic flow in the road network, and provide good services for the safe and rapid driving of drivers. Combined with the actual situation of Shenzhen City, the system takes the shared information platform as the data support, integrates the advanced traffic concept and mathematical model concept, establishes the arterial traffic guidance model, optimizes and calculates all kinds of information such as traffic flow, delay time and travel time, automatically generates guidance

information, and automatically publishes large screens to travelers in real time through VMS, which lays the foundation for the construction of vehicle guidance, and can implement the dynamic information publishing function.

5. Parking Guidance System: Parking guidance system is a part of the whole urban traffic guidance system. Through the comprehensive analysis of the road network, arterial traffic flow, parking distribution, and parking spaces in the area, the driver is guided to choose parking spaces and driving lines from blind driving, which effectively reduces the invalid driving caused by parking, so as to comprehensively alleviate local traffic congestion and balance road network traffic flow. At present, the construction of Prince Shucheng subdistrict and People's Nanzi subdistrict has been completed, including 9 parking lots and 18 parking guidance cards. South of the people's access to 39 parking lots, set up 58 parking guidance signs.
6. Common Information Platform: Common information platform is the basic subsystem of ITS, an important basis for decision-making of other subsystems, and a key technology to realize the transformation of traffic management from simple static management to intelligent dynamic management. The shared information platform is a communication network platform established to meet various traffic information needs by formulating the interface and functional connection requirements between subsystems of intelligent traffic management system. The shared information platform strengthens the comprehensive processing capacity of traffic information and facilitates the decision-making of traffic managers and travelers. The common information platform takes the traffic model library as the main body, uses the data warehouse technology, carries on the quantitative analysis to the traffic data, through the quantitative analysis, enhances the decision-making science, provides the plan or the data support for the traffic control and the management decision-making, provides the traffic condition and so on various kinds of basic data for ITS each system, provides the traffic data report for the traffic management department such as the monitoring center, the command center, and provides the basic statistical analysis report for the traffic decision-makers.

7.2.6.3 Intelligent Traffic Management System of Wuhan

Wuhan city actively promotes the construction of intelligent traffic management system, establishes the "five centers" of urban traffic fine management, and realizes the transformation from administrative order-driven work to information instruction-driven work. The five centers are mainly composed of the following five parts:

1. Big Data Center. The main duties of big data center include:

   Collecting data: Implement intelligent perception plan, vigorously promote the construction of vehicle networking and electronic identification of transportation facilities, and improve the front-end traffic data collection capacity; integrating resources, integrating data of functional departments such as transportation, planning, urban management, water affairs, education, and meteorology with the Municipal Network Information Office. They signed strategic cooperation agreements with Didi Travel and other Internet companies to collect and summarize Internet data. At present, a total of more than 200 types of traffic data are collected to form a "big data pool." Nearly 700 million new data are added daily, which lays a solid foundation for the three-dimensional description of the relationship between people, vehicles, and roads in Wuhan.

Data Analysis: The construction of Wuhan Traffic Management Cloud Platform and the industry optimal algorithm is used to provide accurate analysis of big data for traffic travel, government affairs, and management. At present, 22 functions such as traffic information release, government service, and traffic management have been realized.

Application Data: Through data analysis, the data are transformed into intelligence and instructions, which directly serve accident prevention, blocking removal and order management, and truly make decisions with data and speak with data.

Leading Innovation: In the big data center, two joint venture studios, Jiangbei and Jiangnan, are set up to invite enterprises and universities to enter, deeply integrate practical needs with frontier technologies, and jointly innovate high-end and deep applications of big data in the field of transportation and management.

2. Information Command Center: The command room, research and judgment room, video studio, traffic order optimization room "four rooms in one," so that the intelligence information network collection, full source combing, full judgment, on the basis of the original command center function, the "intelligence, command, service" integration, the formation of intelligence information research and judgment, command dispatching, service organization, rapid response, evaluation feedback closed loop mechanism. The city's traffic police, auxiliary police, and social rescue forces do "one map display, one key dispatching, one call."
3. Safety Risk Control Center: Establishing risk control center, carrying out traffic safety prediction, monitoring and evaluation in advance, responsible for risk prediction and early warning, supervision of source management, guidance of precision strike, accident depth investigation, promoting coordinated governance, security theory research, and so on.
4. Law Enforcement Supervision Center: The "data police gauge" platform is built to correlate and compare the data of mobile law enforcement terminals such as digital radio, PDA, alcohol tester, and law enforcement recorder, so as to realize the real-time upload of law enforcement video, law enforcement data, and real-time alarm of law enforcement anomalies. The whole process of police law enforcement on duty is traceable and can be closed-loop managed. Next, the functions of law enforcement supervision center will gradually expand to team management, discipline inspection and supervision, performance management, and become the performance evaluation center of the traffic police force.
5. Public Relations Linkage Center: The traffic management department of Wuhan has set up a public relations linkage center, set up a public opinion cloud platform, adhere to the "people have to call, I have to respond," from the masses of the most

resentment, the most hope, the most urgent things. Through the public opinion cloud platform to gather 14 different channels of public opinion, so that the full collection of public opinion, full processing, full feedback. The establishment of news public opinion studio, on the one hand, to strengthen the propaganda report. The organization carried out the “three concessions” concentrated publicity in the city, advocating motor vehicle courtesy zebra line, courtesy emergency channel, courtesy special channel around the campus (convenient for students to take the vehicle to go the special channel, allowing stop and go). Through the “Wuhan good driver” selection activities, traffic illegal rectification “micro broadcast” and other activities, we can improve the citizens’ awareness of civilized traffic, establish the authority of the rule of law, and advocate civilized travel. On the other hand, strengthen public opinion guidance. Through authoritative publication, speech guidance, and hot spot transformation, the emotions of citizens and netizens are guided to the fact.

Based on the “five centers” of urban traffic fine management, the main systems established in Wuhan are as follows:

1. Wuhan Public Security Bureau Public Security Traffic Intelligent Integrated Control System: Through the unified interface specification and adaptive access service, the system collects individual vehicle (identity/behavior) traffic information of each card port and electric police manufacturer located in the provincial/city/county (each core area) entrances and exits, high-speed national and provincial highway entrances, urban sections or intersections, and realizes the aggregation, analysis, storage and application of vehicle information in large-scale, high-density, continuous, and long-term road network. For the business application of public security traffic management, the system provides quasi-real-time inspection and control alarm (interval speeding, annual inspection, to be scrapped) and group vehicle traffic characteristics analysis (traffic flow, average travel time, OD) applications for individual traffic illegal suspected vehicles. For public security, the system provides early warning and screening applications for suspected vehicles (high-risk suspected vehicle warning, series and parallel suspected vehicle analysis, accompanying vehicle analysis, and suspected vehicles at the scene of the incident). The system uses cloud computing and big data technology, which is suitable for cities with more installations and large traffic volumes of trucks and electric police equipment. The system can deeply mine massive data, and has strong parallel expansion ability. The calculation ability of the system does not decrease with the increase of time and data volume.
2. Wuhan Static Traffic Management Comprehensive Analysis System: The static traffic management comprehensive analysis platform of Wuhan Traffic Management Bureau is an important business application system of Wuhan Traffic Management Bureau. Under the constraints of the unified standard and standard system of Wuhan Traffic Management Bureau, it integrates the unified system management and safety management system of Wuhan Traffic Management Bureau, and shares the existing public support environment and resources of Wuhan Traffic Management Bureau. The system releases parking information

such as the number of available parking spaces and parking lot information through a variety of channels to provide parking guidance services for the public, including roadside parking guidance screens, and Internet applications such as auto-navigation. Full information sharing is achieved with traffic control command and dispatch system, inspection and distribution control system, public security and other application systems, public security bureau application system, and the police magic cube to be built. The static traffic management comprehensive analysis platform is responsible for the collection of static traffic information within the scope of traffic management, and provides data support for other systems to maximize the benefits of data applications. Form a close business linkage with the inspection and control system, strengthen vehicle-related security management capabilities, and make full use of the powerful capabilities of the inspection and control system to strengthen static traffic management capabilities.

3. App System of Wuhan Yixing River City: The app system of Wuhan Yixing River City in cloud is an intelligent traffic comprehensive service platform developed and constructed by using advanced computer, GIS, mobile Internet, and cloud computing technology, which realizes information sharing and exchange between traffic-related business departments. The project platform is based on the urgent problems of urban traffic (such as congestion, public travel information service, self-service business processing, etc.), with the basic purpose of improving government service ability and management level, ensuring smooth road and traffic safety, serving public travel, and facilitating public life. Provide comprehensive travel information services for the public to promote the harmonious development of urban people, vehicles, and roads. The system mainly provides comprehensive information services for public security traffic control users, social travelers, and third-party company users. With the thinking of "Internet + transportation," the system focuses on public travel demand, integrates transportation travel service information, provides comprehensive transportation services for the public, expands the coverage of information services, realizes intelligent transportation guidance, and makes public travel more convenient and efficient.
4. Wuhan Traffic Operation Coordination Command Center: Wuhan Traffic Operations Coordination Command Center (TOCC) specifically includes one large-screen display system, two infrastructure projects, and three business application platforms. The comprehensive traffic operation monitoring platform realizes the comprehensive monitoring of the city's traffic operation status and the thematic monitoring of administrative behavior supervision; Integrated traffic vehicle positioning information analysis platform to achieve the city 's ground bus, taxi, "two passengers and one management," integrated traffic emergency daily management, emergency disposal and mobile applications, and display TOCC project results on large screen and computer desktop.

7.3 Overview of Intelligent Traffic Signal Control System

7.3.1 Brief Introduction of Traffic Signal Control System

7.3.1.1 Development Process

Traffic signal control is a traffic management measure that assigns traffic rights to conflicting traffic flows in time by means of various control hardware and software devices (such as artificial, traffic signal lights, electronic computers, etc.) in places where traffic flow space separation cannot be achieved (mainly intersections). Reasonable traffic signal control can reduce traffic congestion, ensure smooth urban road and avoid traffic accidents.

As early as the nineteenth century, people began to use signal lights to direct vehicles on the road and control the order of vehicles passing through intersections. In 1868, the British pioneered signal control on the road. In London, a gas lamp that alternately sheltered red and green glass was used as a signal lamp for traffic control. In 1914, Cleveland in the United States began using an electric light source timing signal machine. In 1917, Salt Lake City introduced an interconnected signal system, and then New York, Chicago, and other cities began to appear manually controlled red, yellow, and green three-color signal lights. In 1926, the British set up the first automatic traffic signal machine in Wolverhampton, which laid the foundation of urban traffic signal automatic control. In 1928, the United States developed the world's first inductive signal machine, and the flexible coordinated timing control system was born. For the first time, it realized the adjustment of traffic signal time according to traffic flow. In 1952, Denver developed a signal network timing scheme selective signal control system by using analog computers and traffic detectors. In 1959, Toronto, Canada, carried out experiments and established a set of traffic signal control system (UTC) controlled by IBM650 computer in 1963. For the first time, computer technology was applied to traffic control, greatly improving the performance and level of the control system, marking the development of urban traffic signal control has entered a new stage.

In the 1960s, all countries in the world successively applied computer technology to traffic control, studied the signal linkage coordinated control system with large control range, established the mathematical model to simulate the traffic flow situation, so as to effectively alleviate the increasingly tense urban traffic problems, and developed many signal control systems. Typically, the Traffic Network Study Tool (TRANSYT) system developed by the British Institute of Transport and Road in 1966, the Sydney Coordinated Adaptive Traffic System (SCATS) system developed by Australia since the 1970s, and the Split Cycle Optimization Technique (SCOOT) system developed by the British Institute of Transport and Road in conjunction with three companies in the early 1970s. After the 1980s, with the development of information technology, urban traffic control began to develop toward informatization and intelligence. In the 1990s, developed countries have begun to appear intelligent traffic control system, and urban traffic control system into the intelligent transportation system, become an important subsystem of advanced traffic management system. As of 2000, more than 480 major cities in the world have adopted advanced traffic signal control systems.

Since the end of the twentieth century, with the continuous development of information technology and control technology, a variety of new control systems have emerged in response to various traffic conditions, such as Real-Time Adaptive Control System (RT-TRACS) system, Strategic Real Time Control for Megalopolis Traffic (STREAM) system, Method for the Optimization of Traffic Signal in Online Controlled Network (MOTION) system, Signal Management in Real Time for Urban Traffic Networks/Traffic-responsive Urban Control (SMART NETS/TUC), etc. China has basically established regional traffic control systems in cities at the provincial capital level through introduction or independent research and development.

7.3.1.2 Genealogical Classification

The development of traffic control is a process of continuous practice. In the process of practice, people put forward and developed many different types of traffic control methods and control systems, and classify traffic signal control systems from different angles.

1. Classification by control method

Traffic control can be divided into timing control, induction control, and adaptive control according to the methods method.

Timing Control: Timing control refers to the operation of the traffic signal controller according to the preset timing scheme. The scheme divides the day into several periods. According to the historical average traffic flow data of different periods in the day, the signal control parameters such as long cycle and green signal ratio corresponding to different periods are calculated offline. Single-stage timing control with only one timing scheme a day. One day according to the traffic volume of different periods of several timing scheme is called multistage timing control.

Actuated Control: Actuated control refers to a traffic control method that sets vehicle detectors on the intersection inlet, and the traffic signal controller can adopt appropriate signal display time to meet the traffic demand according to the real-time traffic flow at the intersection detected by the detector. The timing scheme of the signal lamp in this way is calculated by a computer or an intelligent signal controller, and can be changed at any time with the traffic information detected by the detector. Depending on the location of the detector, it can be divided into semi-actuated control and fully-actuated control.

(a) Semi-actuated Control: Semi-actuated control refers to the actuated control that only detectors are set on some inlet roads (generally secondary roads) intersections.

(b) Fully-actuated Control: Fully-actuated control refers to the actuated control that detectors are set on all inlets of the intersection.

Adaptive Control: Adaptive control refers to a control method that regards the traffic system as an uncertain system, and the system can continuously measure its state (such as traffic flow, parking times, delay time, queue length, etc.), track and predict the change trend of traffic state, change the adjustable parameters of the system or generate a control scheme for a certain control goal, so as to achieve the optimal or suboptimal control effect. According to the different control methods, it can be divided into decision-selection and decision-generation.

(a) Decision-selection: The decision-selection refers to that the corresponding control strategies and schemes are stored in the computer in advance corresponding to different traffic flows. When the system is running, the most suitable control strategies and schemes are selected according to the real-time collected traffic flow data to implement traffic signal control.
(b) Decision-generation: The decision-generation refers to calculating the optimal traffic control parameters in real time according to the real-time collected traffic flow data, forming the signal control timing scheme, and immediately manipulating the signal controller to operate the traffic signal lamp according to this Scheme.

2. Classified by control range: Traffic control can be divided into single point control, arterial coordination control, and regional coordination control according to the spatial range involved in the control.

Single Point Control: Single point control is referred to as point control, which means that the traffic signal control at each intersection only operates independently according to the traffic situation of the intersection, and does not exchange any information with its adjacent intersections. It is the most basic form of traffic signal control at the intersection. The point control is applicable to the situation where the distance between adjacent intersections is far, the line control effect is not large, or because the traffic demand of each phase changes significantly, the long cycle of the intersection and the independent control of the green signal ratio are more effective than the line control.

Arterial Coordination Control: The arterial coordination control is referred to as line control, also known as green wave control. It refers to connecting the traffic signals of several continuous intersections on the arterial line in a certain way, coordinating the green light start time and signal timing scheme of traffic signal lights at each intersection, so that the vehicles do not often encounter red lights when passing through these intersections. The basic idea of line control is to set the speed of the section on the specified traffic line, and hope that the vehicle will meet the green light every time it reaches the first intersection. However, in fact, it is difficult to meet the requirements that all roads have green lights because the speed of each vehicle is different and varies at any time, and there are left and right such as left and right turns and vehicle access at the intersection. However, it is possible to make the vehicles along the road encounter few red lights, reduce the parking and queuing delay of most vehicles, and maintain the continuous traffic on the arterial line. The key to line control is that the signal cycle of each intersection must be the same.

Regional Coordinated Control, referred to as "face control," refers to the multiple signal intersections in a region as a whole for mutual coordination, control area of traffic signals are controlled by the traffic control center centralized management control. For regions with small scope, the whole region can be centralized controlled. For a wide range of areas, it can be partitioned hierarchical control. According to the different control strategy and control structure, the regional coordinated control system can be classified as follows:

1. Classified by Control Strategy.

   (a). Timing Off-line Control System: The timing off-line control system uses the historical and current statistical data of traffic flow to optimize off-line processing. The optimal signal timing scheme of multi-period is obtained and stored in the controller or control computer to implement multi-period timing control for the whole regional traffic.

   Timing off-line control system uses historical and current traffic flow statistics to optimize off-line processing, and obtains the optimal signal timing scheme of multi-period, which is stored in the controller or control computer to implement multi-period timing control for the whole regional traffic. The timing offline control system is simple, reliable, and efficient investment ratio is high, but it cannot adapt to the random changes of traffic flow, especially when the traffic data is outdated, the control effect is significantly reduced. When the optimal timing scheme is re-established, traffic investigation will consume a lot of labor. At present, the mature timing offline control systems include TRANSYT, Corridor Simulation (CORSIM), Progression Analysis and Signal System Evaluation Routine (PASSER), etc.

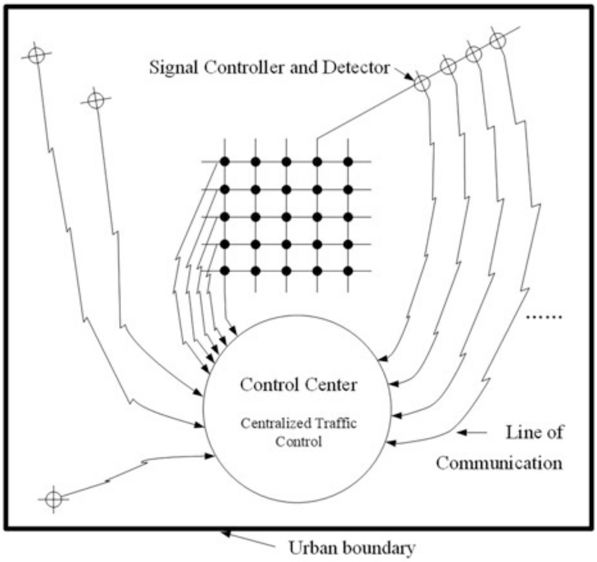
   (b). Actuated Online Control System: Actuated online control system sets up a vehicle detector in the control area traffic network, collects traffic data in real time, identifies the traffic model, and then obtains the optimization problem related to the timing parameters, solves the timing scheme of the problem online, and implements on-line optimal control.

   The actuated online control system can respond to the random changes of traffic flow in a timely manner, and the control effect is good, but the control structure is complex, the investment is high, and the reliability of equipment is high. Currently more mature online control systems are SCATS system, SCOOT system.

2. Classification by Control Structure.

   (a) Centralized Control Structure: Centralized traffic signal control at all intersections in the region is achieved in a control center by connecting all the signal machines in the region into a network, using one small and medium-sized computer or multiple computers online, as shown in Fig. 7.13.
   (b) Hierarchical Control Structure: The entire traffic signal control system is divided into upper and lower subsystems. The upper subsystem receives the

Fig. 7.13 Centralized traffic control system structure diagram [2]



intersection timing scheme from the lower subsystem. These timing schemes are coordinated and analyzed from the overall perspective, so that the timing scheme of the lower subsystem is corrected. The lower subsystem makes necessary adjustments according to the revised scheme. The upper subsystem mainly completes the coordination and optimization task of the whole system, and the lower subsystem mainly completes the execution task of intersection timing adjustment in the region. The hierarchical control structure is generally divided into three levels, as shown in Fig. 7.14.

The first level is located at the intersection and is controlled by a signal controller. Its functions should include: (a.) monitoring equipment failures (detectors, signal lights, and other local control facilities); (b.) collection and aggregation of test data; (c.) transmission of data on traffic flows and equipment performance to second level of control; (d.) receive and operate instructions issued by superiors.

The second level is located in a relatively central position in the controlled area, and its functions should include: (a.) monitoring the data of traffic flow and equipment performance from the first-level control and transmitting them to the third-level control center; (b.) manipulate the first-level control, determine the type of control to be implemented (single-point control or regional control), select control methods, and coordinate the first level control.

The third level is located in a reasonable center of the city, and should act as a command and control center, responsible for the coordinated control of the whole system. The control center can monitor the data of any signalized intersection in the control area, receive and process the data of traffic flow conditions, determine the control strategy of the second-level control, and provide monitoring and display

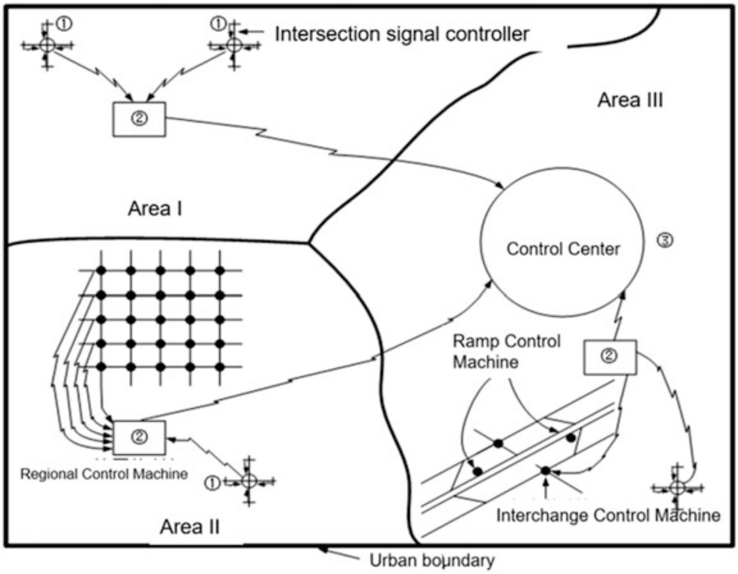


Fig. 7.14 Layered traffic control system structure diagram [2]

equipment. In addition, the control center can receive information on equipment failures in order to take appropriate measures.

7.3.2 *Typical Intelligent Traffic Control System*

In order to adapt to the rapid increase in traffic volume and alleviate road traffic congestion, many cities in China and abroad have invested a lot of labor and material resources in the research and development of traffic signal control system, and have achieved a series of results. Among them, the more successful systems are SCATS (Australia), SCOOT (UK), Real-time Hierarchical Optimized Distributed and Effective System (RHODES, USA), Signal Progression Optimization Technology (SPOT)/Urban Traffic Optimization by Integrated Automation (UTOPIA, Italy).

7.3.2.1 SCATS System

SCATS is a real-time scheme selection adaptive control system developed by the Roads and Transport Agency (RTA) of New South Wales, Australia. It has been studied since the 1970 s and has been put into use in Sydney and other cities since 1980.

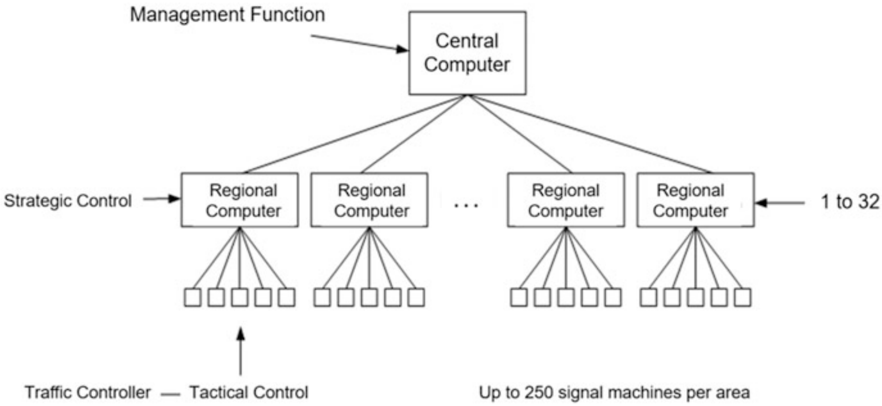


Fig. 7.15 SCATS system structure diagram [3]

1. Structure of SCATS System

   The control structure of SCATS is hierarchical three-level control. The highest level is the central monitoring center, the middle level is the regional control center, and the lowest level is the signal control machine. When a signal controller is controlled by a regional control center, usually every 1–10 signal controllers are combined into a "subsystem," and several subsystems are combined as a relatively independent system. The systems are basically irrelevant of each other, and there is a certain coordination relationship between the various subsystems within the system. With the real-time changes in traffic conditions, the subsystems can be combined or re-separated. The choice of the three basic timing parameters is based on the subsystem as the accounting unit. The structure of SCATS system is shown in Fig. 7.15.

   The central monitoring center, in addition to the centralized monitoring of the operating status of the entire control system and the working status of various equipment, also has a computer dedicated to the management of the system database to monitor the various data of all regional control centers and the control of each signal control machine. Operating parameters are dynamically stored (in the form of a constantly updated dynamic database). Traffic engineers can not only use these data for system development, but also all the development and design work can be completed on the machine (off-line work mode).

   While SCATS implements the overall coordinated control of several subsystems, it also allows each intersection to "work independently" and independently implement vehicle induction control. The former is called "strategic control," and the latter is called "tactical control." The organic combination of strategic control and tactical control greatly improves the control efficiency of the system. SCATS uses the vehicle detection device set near the parking line to control the traffic effectively and flexibly in this way. Therefore, SCATS is actually a scheme selection control system that uses induction control to make partial adjustments to the timing Scheme.

2. Signal Timing Parameter Optimization of SCATS System

The following part briefly introduces the main links of the signal timing parameter optimization of the SCATS system.

(a) Division and Combination of Subsystems

The division of subsystems by SCATS is determined by traffic engineers according to the historical and current data of traffic flow, and the environment and geometric conditions of the transportation network, and the established subsystems are the basic units of the control system. In the process of optimizing timing parameters, SCATS uses the "merging index" to determine whether adjacent subsystems need to be merged. In each signal cycle, the "merging index" needs to be calculated once. When the difference of signal cycle time required by the two adjacent subsystems is not more than 9 s, the cumulative value of "merging index" is "+1," otherwise is "−1." If the cumulative value of the "merge index" reaches "4," it is considered that the two subsystems have reached the merged standard. The merged subsystem can be automatically redivided into the original two subsystems when necessary, as long as the cumulative value of the "merging index" drops to "0."

After the subsystems are merged, the signal cycle duration of the new subsystem will adopt the longer of the signal cycle durations performed by the original two subsystems, and the other of the original two subsystems will then slow down or accelerate the growth of its signal cycle. Speed until the "external" phase difference scheme of these two subsystems is realized.

(b) SCATS Timing Parameter Optimization Algorithm

SCATS takes the subsystem composed of 1–10 intersections as the basic control unit, and these intersections have a common cycle length. On each entrance lane of all intersections, a vehicle detection device is installed, and the detection device (such as an inductance coil) is separately installed behind the stop line of each lane. According to the real-time traffic volume data provided by the vehicle detection device and the actual traffic volume of the parking line section during the green light period, the algorithm system selects the common cycle time of each intersection in the subsystem, the green signal ratio and phase difference of each intersection. Considering the possibility of merging adjacent subsystems, it is also necessary to select an appropriate phase difference for them (the phase difference outside the subsystem).

As a real-time scheme selection control system, SCATS requires that the control area be divided into several subregions in advance according to traffic conditions by using offline calculations in advance. According to the measured traffic data inside the subregions, four green signal ratio schemes, five internal phase difference schemes (referring to the relative phase difference between the intersections in the subsystem), and five external phase difference schemes (referring to the phase difference between adjacent subsystems) are developed for each intersection. The real-time selection of signal cycle and green signal ratio is based on the overall needs of the subsystem, that is, the length of the shared cycle is determined according to the needs of key intersections in the subsystem. The corresponding green time of the intersection determines the percentage of each phase of green light in the signal cycle according to the principle of equal or close saturation of each phase. Obviously, with the adjustment of signal cycle, the green time of each phase also changes, and under the condition that the scheme remains unchanged, according to the actual measurement situation, the green signal ratio and phase can be slightly adjusted to adapt to changes in traffic flow.

SCATS selects the signal period, green signal ratio, and phase difference as independent parameters, and the algorithm used in the optimization process is based on "class saturation" and "comprehensive flow."

- Degree of Saturation

The Degree of Saturation (DS) used in SCATS refers to the ratio of green light time which is effectively used by traffic flow g' to green light display time g. The calculation formulas of DS and g' is as follows:

$$DS = \frac{g'}{g} \tag{7.3}$$

$$g' = g - (T - th) \tag{7.4}$$

where DS refers to the Degree of Saturation, g means the total time of display green light for vehicle traffic (s), g' means green light time effectively used by vehicles (s), T means the time when there is no car on the parking line during the green light (s), t refers to a necessary idle time between the front and rear vehicles when the traffic normally passes the section of the parking line (s), h means the essential null number, and parameters g, T, and h can be provided directly by the system.

- Comprehensive Flow

Since the vehicle detection coil used in SCATS system is as long as 4.5 m, the detection accuracy of the vehicle throughput is affected, especially when traffic congestion occurs at the intersection. In order to avoid using parameters directly related to vehicle type (body length) to represent traffic flow, SCATS introduces a virtual parameter called "comprehensive flow" to reflect the number of mixed traffic flows through the parking line. The integrated flow rate q' refers to the converted equivalent of vehicles passing through the stop line during a green light period. It is determined by the directly measured class saturation DS and the maximum flow rate S that actually occurred during the green light period. The calculation formula is as follows.

$$q' = \frac{DS \times g \times S}{3600} \tag{7.5}$$

where q' means comprehensive flow (veh), and S refers to the maximum demand recorder flow rate (veh/h).

(c) Selection of Signal Cycle Time

The selection of the signal cycle time is based on the subsystem, that is, within a subsystem, the cycle time that the entire subsystem should use is determined according to the intersection with the highest class saturation. SCATS is equipped with vehicle detectors on each inlet lane of each intersection. The largest DS value measured directly by each detector in the previous cycle is taken out, and the cycle length that should be used in the next cycle is determined accordingly.

In order to maintain the continuity of signal control at intersections, the signal cycle is adjusted in continuous small steps, that is, the length of a new signal cycle is limited to ± 6 s compared with the previous cycle.

For each subsystem range, SCATS requires four limits of signal cycle change, namely, the minimum value of signal cycle ($C_{\min}$) and the maximum value of signal cycle ($C_{\max}$), which can obtain the medium signal cycle duration (C_s) with good continuity of two-way traffic in the subsystem range and the signal cycle (C_x) slightly longer than C_s. In general, the selection range of signal period is only between $C_{\max}$ and Cs. Only when the traffic flow arrival detected by the vehicle detector at the key position is lower than the predetermined limit, the signal period value less than Cs and even $C_{\min}$ is adopted. The signal period higher than C_x is determined by the "critical" import lane detection data (*DS* value). These "critical" lanes are significantly higher than other lanes, requiring more green light release time, and thus need to get "preferential" lanes from the increase of the signal cycle.

(d) Choice of Green Ratio Scheme.

In SCATS, the selection of green ratio schemes is also based on subsystems. Four green ratio schemes were prepared for each intersection for real-time selection. These four schemes aim at the ratio of each phase green light time to the signal cycle length (usually expressed as percentage) under four possible traffic loads. In each green signal ratio scheme, not only the time of green lights in each phase is stipulated, but also the order of green lights in each phase is stipulated. In different green signal ratio schemes, the order of signal phase may be different, that is, in SCATS, the order of intersection signal phase is variable.

In the green signal ratio scheme of the SCATS system, the flexibility of multiple choices is also provided for local tactical control (vehicle induction control mode at unit intersection). Affected by fluctuations in traffic arrival rates, some phases may have surplus green time under the established green signal ratio scheme, while others may have insufficient green time allocated. Therefore, without lengthening and reducing the signal cycle time, it is possible and necessary to make a reasonable residual and deficiency adjustment for the green light time of each phase changing with the real-time traffic load. This requires specific provisions on possible adjustment methods in the green credit ratio scheme. At some intersections, the green light time of some phases may not be suitable for shortening due to the requirements of vehicle induction control. Then, in the plan, pay special attention to the green light time of these phases, which can only be lengthened but not shortened.

The selection of green signal ratio scheme should be carried out once in each signal cycle, and the general process is as follows. In each signal cycle, four green signal ratio schemes are compared and their "selection" is "voted." If a program is "elected" twice in three consecutive cycles, it is selected as the implementation program for the next cycle. In an inlet lane, only the lane with the highest *DS* value is considered as the green signal ratio.

The selection of the green signal ratio scheme is interleaved with the adjustment of the signal period. Combining the two, the result of continuous adjustment of the green light time of each phase, so that the saturation *DS* of each phase is maintained at approximately the same level, which is the "equal saturation" principle.

(e) Selection of Phase Difference Scheme.

In SCATS, the internal and external phase difference schemes must be determined in advance and stored in the central control computer. Each category contains five different programs. During the operation of the system, the phase difference must be selected in real time for each signal cycle. The specific steps are as follows.

In the subarea, the first scheme of the five phase difference schemes is only used in the case that the signal cycle time is exactly equal to $C_{\min}$. The second scheme is only used when the signal period satisfies $C_s < C < C_s + 10$. The rest three schemes are selected according to the real-time detected comprehensive flow value. For each relevant entrance road, the traffic flow and saturation that the inlet can release should be calculated when three phase difference schemes (the third, fourth, and fifth schemes) are implemented respectively, which is essentially similar to the widest passband method. SCATS is to compare the green wave bandwidth provided to each entrance road by the above three schemes. The larger the passband width can be provided, the more obvious the superiority of this scheme is. After comprehensive comparison, the most superior phase difference scheme is selected. Four selected options in five consecutive cycles were selected as new ones for implementation.

The external phase difference scheme is also selected in the same method as the internal Scheme.

3. Characteristics of SCATS System.

   SCATS systems have the following characteristics.

   (a) The detector is installed in the stop line and there is need to establish a traffic model, so its control scheme is not model based.
   (b) The optimization of periodic length, green ratio, and phase difference is based on the measured class saturation value in a number of predetermined schemes.
   (c) The system can change the phase sequence according to the traffic demand or skip the next phase (if there is no traffic request for this phase), so it can respond to the traffic demand of each cycle in time.
   (d) It can automatically divide the control sub-zone and has the function of local vehicle induction control.
   (e) Each cycle can change the cycle time.

The disadvantages of SCATS system include the following.

(a) The traffic model is not used, which is essentially a real-time plan selection system, which limits the degree of optimization of the timing plan and is not flexible enough.
(b) The detector is installed near the stop line, and it is difficult to monitor the movement of the vehicle fleet. Therefore, the optimal reliability of green time difference is poor.

7.3.2.2 SCOOT System

SCOOT stands for "green signal ratio-periodic-phase difference optimization technique." And it is a real-time scheme generative adaptive control system. It was jointly developed by the British TRL (Transport Research Laboratory, TRL) and three companies in 1973, and was officially put into use in 1979. After years of development, the SCOOT system has been upgraded many times, and more than 200 cities around the world are currently using the system.

Principle and Structure of SCOOT System

SCOOT processes the vehicle arrival information collected by the vehicle detector installed at the exit of the upstream intersection online, forms the control scheme, and adjusts the parameters such as green signal ratio, cycle time, and phase difference in real time to adapt to the changing traffic flow. The system is mainly composed of four parts: the collection and analysis of traffic data, traffic model, optimization and adjustment of traffic signal timing parameters, control of the signal system.

All calculation and analysis in SCOOT system are based on periodic flow diagram, which can be calculated by SCOOT program. The diagram of periodic flow change is a histogram of the change of traffic volume with time in a cycle, which is represented by the ordinate and the abscissa (limited by the length of a cycle).

In order to facilitate calculation, a signal cycle is usually divided into several periods, each period is about 1 s to 3 s. In the SCOOT traffic model, the basic data of all the calculation process are the average traffic volume, turn traffic volume and turn length of each period. In order to describe the whole process of traffic flow running on a line, SCOOT uses the following three types of cycle flow diagrams.

1. Arrival flow diagram (referred to as the arrival diagram). This diagram shows the change in the arrival rate of the traffic to the downstream stop line without being blocked.
2. Exit flow diagram (referred to as exit diagram). This graphic depicts the changes in actual traffic flow as it leaves the upstream intersection.

3. Saturated exit diagram (referred to as full flow diagram). The “full flow” diagram is actually a flow diagram that leaves the stop line at a saturated flow rate. This icon appears only when the traffic flow passing through during the green light is saturated.

SCOOT system is based on real-time measured traffic data and uses traffic models to optimize timing. The system processes the traffic volume information collected by the vehicle detector to form the Cyclic Flow Profiles (CFP), which is then combined with the static parameters pre-stored in the computer, such as the running time of the fleet on the connection, the signal phase sequence and the phase time wait for calculation in the traffic model together. The SCOOT optimization program thus calculates the best combination of signal timing, and the obtained optimal timing plan is immediately sent to the signal machine for execution.

SCOOT optimization uses a small step size asymptotic optimization method, which does not require too much calculation, so that it can follow the instantaneous change of CFP, that is, the signal timing can be changed slightly with the change of CFP, which can ensure the timing of the timing plan. The adjustment will not cause major disturbance to the operation of traffic flow, but it can add up to produce a new coordinated control mode in time.

In addition, SCOOT has special monitoring and response measures for the possible traffic congestion and congestion on the road network. It can not only monitor the working state of each component of the system at any time, and give an automatic alarm for the fault, but also provide operators with details of the signal timing scheme being executed at each intersection, the queuing situation of vehicles in each cycle (including the actual position of the queue tail) and the flow arrival schema and other information at any time. It can also automatically display these information on the terminal equipment.

SCOOT system is a two-level structure. The upper level is the central computer, and the lower level is the intersection signal machine. Traffic volume prediction and timing optimization are completed on the central computer, signal control, data collection, processing, and communication are completed on the signal machine. The structure of the system is shown in Fig. 7.16.

Signal Timing Parameters Optimization of SCOOT System

The following is a brief introduction to the four main links of the SCOOT system’s optimized timing plan.

1. Detection

- Detector

SCOOT uses ring coil detector to detect traffic data in real time. In order to avoid leakage and retest, the coil adopts 2 m × 2 m square ring. When parking is not allowed at the roadside, it can be buried in the middle of the lane. Sensors should be

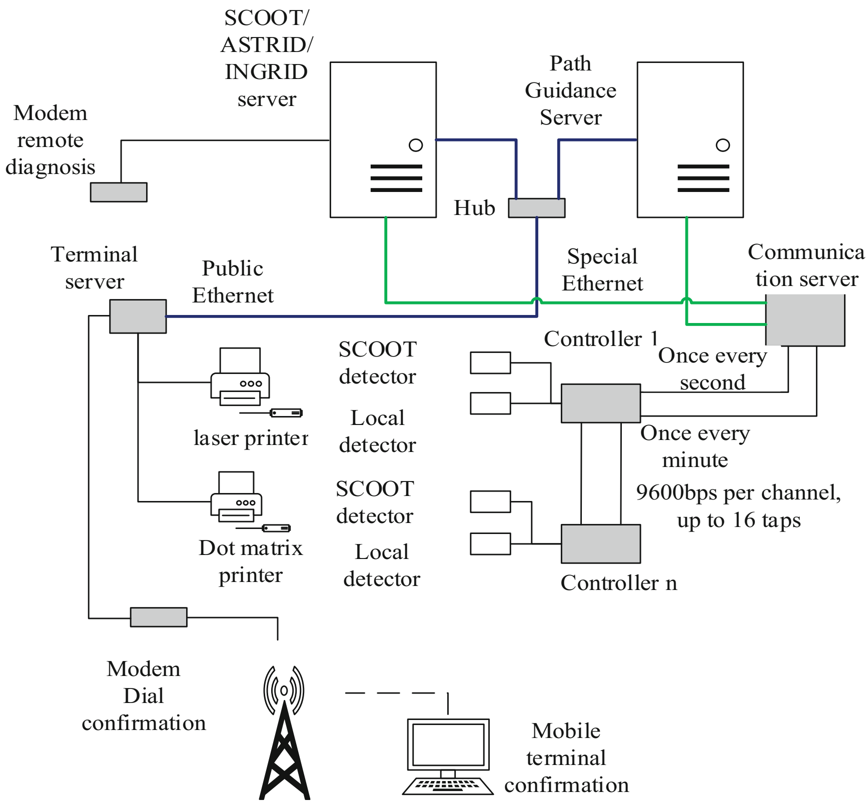


Fig. 7.16 SCOOT system structure diagram [4]

buried in all lanes. One sensor detects one or two lanes. When two lanes share one sensor, the sensor can be located across the middle of the lane.

- Appropriate Location of the Detector

Through real-time detection, SCOOT can achieve the purpose of real-time prediction of traffic flow pattern and system performance index (PI value) on the parking line. Therefore, the appropriate location of the detector is the place as far as possible from the downstream parking line, which is usually set at the exit of the upstream intersection. When choosing the location of the detector, the following factors should be considered.

(a) When there are branch lines or intermediate entrances and exits between the two intersections, and the traffic volume is greater than 10% of the traffic flow of the arterial line, the detector should be installed as far as possible at the downstream of the branch or intermediate entry and exit, otherwise supplementary detectors should be set at the branch or intermediate entrances and exits.

(b) The detector should be located downstream of the bus stop to avoid other vehicles missing detection due to detours.
(c) The detector should be located downstream of the sidewalk. Considering that the speed requirement of the vehicle passing through the detector is basically equal to the average speed of the section, the sensor should be at least 30 m away from the pedestrian crossing.
(d) The detector is set at a distance from the downstream parking line at least equivalent to 8 ~ 12 s of driving time or more than the maximum queue length of vehicles in a cycle.

The advantages of setting detectors in this way include:

(a) It can detect the current cycle flow in real time, and predict the cycle flow chart to the parking line in real time.
(b) Real-time detection of the current cycle queue length to avoid aggravating traffic jams caused by vehicles passing the upstream intersection.
(c) It can detect the degree of vehicle congestion in real time.

The disadvantage of setting up the detector in this way is that it is not as good as setting it close to the parking line to detect the saturated flow and perform the function of actuated control in real time.

- Collection of Traffic Data

The traffic data that SCOOT detector can collect include the following:

(a) Traffic volume.
(b) Occupy time and occupancy rate. Occupied time is the time when the detector senses the vehicle passing, and the occupancy rate is the ratio of occupancy time to the entire cycle time.
(c) The degree of congestion. Measured by the occupancy rate of the hindered vehicle fleet, SCOOT divides congestion degree into eight grades (0–7) according to occupancy rate, which is called congestion coefficient. Congestion coefficient is sometimes one of the goals of SCOOT timing optimization.

In order to accurately collect the time when the sensor passes through the vehicle or not, the sampling period should be short enough. The SCOOT detector automatically collects the induction signals of each sensor every 0.25 s, and analyze and processes it.

2. Division of Subregions

The division of SCOOT system subregions is predetermined by the traffic engineers, and the system operation is based on the delimited subregions. It cannot be combined or divided during operation, but SCOOT can have dual-cycle intersections in the subregions.

3. Model

- Cycle Flow Chart—Vehicle-Group Forecast.

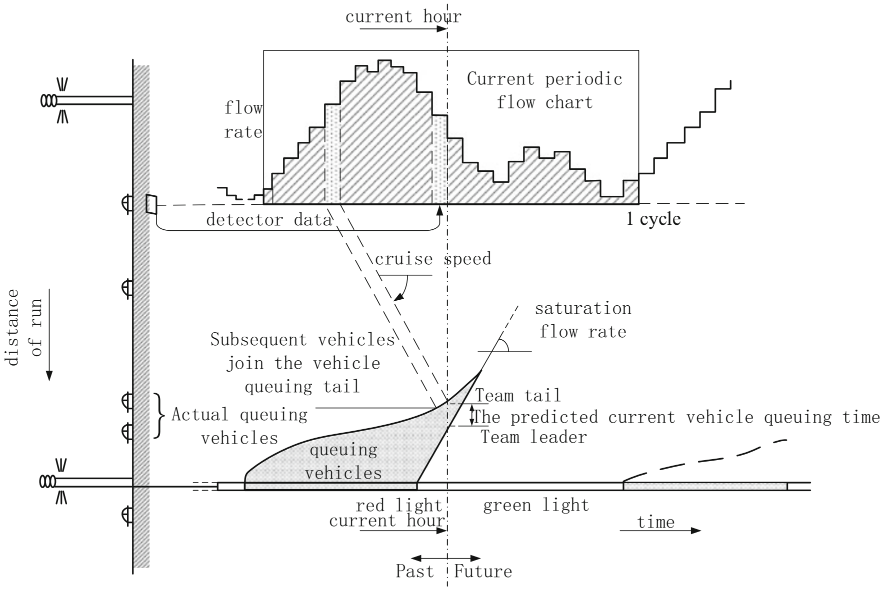


Fig. 7.17 Vehicle queuing forecast schematic [2]

The SCOOT system is processed according to the traffic information (traffic volume and occupancy time) detected by the detector, and then drawn in real time into a vehicle arrival cycle flow diagram on the cross-section of the detector. Then, on the periodic flow chart of the sensor section, through the discrete model of traffic flow, the periodic flow chart that arrives at the stop line is predicted, that is, the “arrival” pattern. The unit of the ordinate of the SCOOT cycle flow chart is lpu (connected traffic chart unit), which is a mixed measurement unit of traffic volume and occupancy time, and its function is equivalent to the conversion function of pcu. Corresponding to the unit of measurement of traffic volume, lpu, the unit of saturated traffic on the parking line is also changed to lpu.

- Prediction of Queue

Figure 7.17 is the principle diagram of vehicle queue length prediction. The upper right side is the “arrival” pattern on the detector section measured by the detector, which is updated every cycle; the lower right side is the predicted queuing diagram on the stop line section. SCOOT controls the time of the signal light by the computer, so the computer understands the current state of the signal light and adds the vehicles during the red light period to the queue. After the green light is on, the vehicle will drive out of the parking line at a certain “saturated flow rate” (prestored in the computer database) until all the vehicles in the queue are dissipated. Since vehicle speed and fleet dispersion are difficult to accurately estimate, the predicted queuing must be inspected and corrected on the spot. The inspection usually compares the actual observed vehicle queuing length with the displayed predicted queuing length, for example, the predicted queuing length has not reached the detection The cross-section of the detector, but the detector is actually occupied by vehicles, indicating that the SCOOT model underestimates the queue length.

- Congestion Prediction

In order to control the queue extending to the upstream intersection, the blocked queue length must be controlled. The traffic model calculates the congestion coefficient according to the occupancy rate of the detection, which can reflect the degree of vehicle obstruction. At the same time, since the SCOOT detector is located on the exit road near the upstream intersection, when the detector detects that there is a car parked on the detector, it indicates that the queue is about to extend to the upstream intersection.

- Effectiveness Prediction

SCOOT uses the weighted sum of delay and parking times, or fuel consumption as a comprehensive efficiency index (PI), but SCOOT sometimes uses congestion coefficient as one of the efficiency indexes.

From the above queuing prediction, SCOOT can predict the delay and parking times under each timing scheme.

The influence of congestion on signal timing optimization increases with the increase of congestion. Consider reducing the degree of congestion in the timing optimization, and the congestion coefficient can also be listed as one of the comprehensive performance indicators. The index used in the comprehensive efficiency index should be determined according to the control strategy. For example, during peak hours, reducing vehicle delay is the main control objective; at short-distance intersections, considering the need to avoid queuing up and blocking upstream intersections, the congestion coefficient can be one of the control objectives.

In addition, SCOOT regards saturation as the basis for the optimal period length, because the saturation decreases (increases) as the period length increases (shortens). When the saturation reaches 100%, serious traffic congestion is bound to occur, so SCOOT controls the saturation not to exceed 90%.

4. Optimization

The signal parameter optimization strategy of SCOOT system is to make frequent and appropriate adjustments to the optimal timing parameters as the traffic arrival volume changes. The appropriate amount of adjustment is small, but due to the frequent adjustments, the continuous accumulation of these frequent adjustments can be used to adapt to the traffic trend in a period of time. This optimization strategy is one of the main reasons for the success of SCOOT, with the following four major benefits.

- Appropriate adjustment of the timing parameters will prevent excessive ups and downs, which can avoid the instability of traffic flow caused by sudden changes in timing.

- Since the timing parameters only need to be adjusted quantitatively, the optimization algorithm is greatly simplified, and the adaptive control of real-time operation can be realized.
- Frequent adjustments avoid the problem of long-term prediction of traffic flow.
- The amount of adjustment of timing parameters each time is not large, but because of frequent adjustments, it can always track the trend of adapting to traffic changes.

The optimization methods of signal parameters (green ratio, phase difference, signal cycle, etc.) are introduced below.

1. Optimization of Green Ratio

   The key points of the optimization of the green ratio are as follows.

   - SCOOT optimizes the green ratio of each intersection individually.
   - A few seconds before the start of each phase, recalculate whether the current green time needs to be adjusted.
   - The adjustment of green light duration takes ±4 s as the step length to optimize the green light duration. In other words, the PI value after adjusting ±4 s is compared with the PI value that maintains the original state. The scheme with the smallest PI value is selected and sent to the signal control machine, which is a temporary change.
   - With each temporary change, the system controller makes a permanent change of ±1 s of the green light duration. After storage, it is used as the starting point of the next change. This trend adjustment is conducive to tracking the traffic change trend in a period of time.
   - In addition, SCOOT also needs to consider the minimum total saturation at the intersection, the length of vehicle queue, the degree of congestion and the limitation of the shortest green light duration when optimizing the green ratio.

2. Optimization of Phase Difference

   The main points of phase difference optimization are as follows:

   - When SCOOT optimizes the phase difference, the unit is the subregion.
   - SCOOT performs a phase difference optimization calculation for each intersection (whether the phase start time changes or not) before each cycle.
   - The adjustment of phase difference is also ±4 s.
   - The method of optimizing the phase difference is the same as that of optimizing the green signal ratio, but the minimum sum of PI values on all adjacent roads is taken as the optimization objective.
   - When optimizing the phase difference, the queue between the short-distance intersections must be considered to avoid the queue tail of the downstream intersection blocking the traffic of the upstream intersection. SCOOT first considers the continuity of traffic between these intersections, and if necessary, it can sacrifice the coordinated control between signals on the long line (which can accommodate large queue vehicles) to ensure that there is no queuing and blocking the upstream intersection on the short line.

3. Length Optimization

   The key points of cycle length optimization are as follows.

- When SCOOT optimizes the cycle length, the unit is the subregion.
- SCOOT calculates the cycle length of each intersection in the subregion every 2.5 to 5 minutes. The cycle length of the key intersection is taken as the shared period length in the subregion.
- The goal of cycle length optimization is to limit the saturation of key intersections in the sub-region to 90%. When the saturation is small, the cycle length decreases, and the capacity decreases, which can increase the saturation. Saturation close to 90%, stop reducing cycle length. When the saturation is large, the cycle length increases, and the capacity increases, which can reduce the saturation.
- The adjustment of period length is ±4 s–±8 s.
- SCOOT considers the selection of double periodic signals when adjusting the cycle length. If the overall PI value is optimal due to the double periodic signals, the selected period length can be adjusted separately.
- SCOOT also needs to consider the upper and lower limits of the signal cycle. The lower limit is mainly for the consideration of traffic safety, taking into account the minimum time required for pedestrians to cross the street safely and the minimum green light time for vehicles to be released at one time. Generally, 30–40 s is the lower limit of the signal cycle. The upper limit is to minimize vehicle delay on the premise of meeting the maximum traffic requirements. The upper limit is determined by the local actual traffic conditions (vehicle type composition, crossroad plane size, and traffic load size, etc.). Overall 90–120 s is commonly used as the upper limit in foreign countries. Due to the large number of bicycles and low-speed large vehicles in China, it can be appropriately relaxed (120–200 s).
- The influence of traffic congestion coefficient is not considered in the cycle length optimization, so the SCOOT system only considers the congestion coefficient in the green signal ratio and phase difference optimization.

4. Improvement

In order to deal with saturated or supersaturated states, SCOOT version 2.4 and above versions have corresponding improvements, mainly including the following points.

- Gate Control

  The main purpose of gate control is to limit the flow of traffic to sensitive areas and redistribute the convoys to roads that can accommodate longer convoys, so as to prevent the formation of long convoys or congestion in the region. In order to realize the sluice control, SCOOT must be able to modify the signal timing of the intersection, which may be far from the relevant area or even in another subarea. Gate logic allows one or more lines to be defined as critical or bottleneck lines. The gate connection is designated as the connection of the storage fleet. Without these connections, the bottleneck connection will be blocked. When the bottleneck connection reaches a predetermined saturation, the green light of the gate connection will decrease.

All control logic is contained in the green ratio optimizer. For a bottleneck connection, traffic engineers need to determine its critical saturation, which can be problematic if exceeded. This critical saturation is used to trigger the gate algorithm. The possible role of the latter is that if the saturation is less than or equal to the critical saturation, and both judgments are so, the gate does not work. If the saturation of the gate is greater than the critical saturation, and the two judgments are the same, the gate will work, usually to reduce the green light time of the gate connection. However, the gate logic may also cause the increase of the green light time of the gate connection downstream of the bottleneck, so as to release the fleet of the gate connection as soon as possible. All changes are governed by the normal green ratio optimizer.

- Saturated Phase Difference

  Under saturation conditions, the phase difference requirement for a connection is different from the requirement under normal conditions (to minimize the delay of the connection). At this time, the setting requirement of phase difference is to maximize the traffic capacity. When the upstream intersection shows the green light to the critical entrance, this connection will not be saturated. When a line is measured saturation, the saturation phase difference will be forced to take, and the phase difference optimizer will abandon its optimization results.

- Use the Information of Adjacent Connections to Deal with the Saturation Problem.

  To solve the saturation problem, one connection can use its own information and the saturation information from another connection together, or only use the latter. If the convoy of a link is too long and reaches the detector of the upstream link, the saturation of the upstream link can be regarded as the result of the saturation of the link. At this time, the upstream link should be regarded as the saturation information source of the link, and the timing plan of the downstream intersection of the link should be adjusted.

Characteristics of SCOOT System

SCOOT system has the following characteristics.

- A flexible and accurate real-time traffic model can be used not only to determine the signal timing scheme, but also to provide various information such as delay, number of stops, and congestion data for traffic management and traffic planning.
- Adopting short-term forecasting form, only forecasting the traffic conditions in the next cycle, and controlling according to the forecasting results, greatly improving the accuracy of forecasting and the effectiveness of control.
- The frequent small increment form is used in the optimization and adjustment of signal parameters, which not only avoids the disturbance caused by the mutation of signal parameters to the vehicle operation in the controlled road network, but

also adapts to the large changes of traffic conditions through frequent cumulative changes.

- The vehicle detector of the system is buried at the exit of the upstream intersection, which provides sufficient time for the optimization and adjustment of the signal timing at the downstream intersection. At the same time, it can prevent the convoy from blocking to the upstream intersection (measures are taken to avoid it before this happens).
- It has the ability to identify the state of the detector. Once the detector fails, it can take corresponding measures in time to reduce the impact of detector failure on the system.

The shortcomings of SCOOT system include:

- The establishment of traffic model requires a large number of road network geometry and traffic flow data, so it is time-consuming and laborious.
- Signal phase cannot be automatically increased or decreased, and phase sequence cannot be automatically changed.
- Saturated flow rate check is not automated, so site installation and debugging are more cumbersome.
- The problem of automatic partition of control subregions has not been solved.

7.3.2.3 RHODES System

Real-time Hierarchical Optimized Distributed and Effective System (RHODES) system was successfully developed by Arizona University in 1996, and field tests were successively carried out in Tucson and Tempe, Arizona. The results show that the system has good control effect on semi-crowded traffic network. The core technology of RHODES system mainly includes three parts, controlled optimization of phase (COP), effective green band (Realband), and prediction algorithms (road network load prediction, road network traffic prediction, and intersection traffic prediction). In the version after 2000, the bus priority function was added by introducing the concept of “Busband.”

Principle and Structure of RHODES System

The Main Principle of the RHODES System: Due to technological advances in the fields of communication, control, and computers, it is possible to quickly transmit and process information and implement multiple control strategies flexibly. The traffic flow changes randomly, and the number of vehicles arriving in the same time interval is also random. This change provides an opportunity to improve the performance of the traffic control system at the intersection control layer; similarly, the number of vehicles in the fleet also changes. This small change also provides an opportunity to improve the performance of the traffic control system. The effect of these opportunities alone to improve the performance of the control system may be

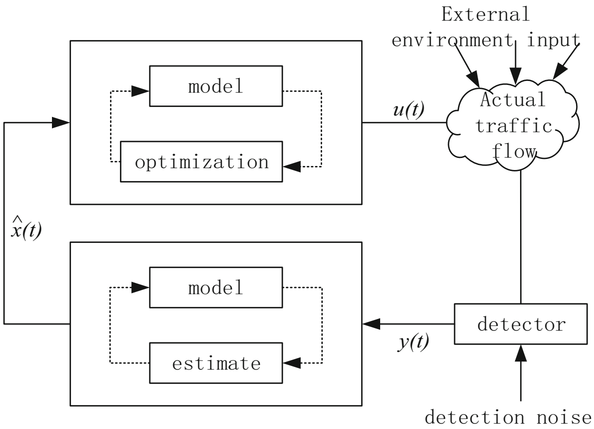


Fig. 7.18 RHODES system principle [5]

insignificant, but if each opportunity is fully utilized, the overall improvement effect will be quite objective. The RHODES system makes full use of this point, obtains the necessary information of the traffic flow in advance through the prediction model, and makes timely and effective responses to it in advance. The system principle is shown in Fig. 7.18.

The Structure of the RHODES System

The RHODES system is a two-level structure in terms of physical structure, namely the central computer level and the signal controller level. From this point of view, it is similar to the SCOOT system. But it decomposes the system control problem into a three-layer hierarchical structure, namely, the intersection control layer, network control layer, and network load distribution layer, as shown in Fig. 7.19.

At the intersection control layer, the traffic flow prediction, phase sequence, and green light duration control are mainly based on the detected traffic flow and various constraints. This control must be performed every second. At the network control layer, it mainly predicts the driving situation of the fleet, so as to establish coordination constraints for each intersection in the network. This prediction is carried out every 200–300 s. At the network load distribution layer, the total traffic demand in a long period (usually 1 h) is mainly predicted, so as to determine the upper bound of the queue length in the future. Many technologies in Advanced Traveler Information System (ATIS) and dynamic traffic flow allocation can be implemented at this layer. Although this distributed structure increases the communication tasks between the intersection controllers, it reduces the calculation tasks of the central controller and the communication tasks with the intersection controllers, and it is easier to implement the communication between the intersection controllers, which makes RHODES's real-time adaptive optimal control of traffic flow becomes possible.

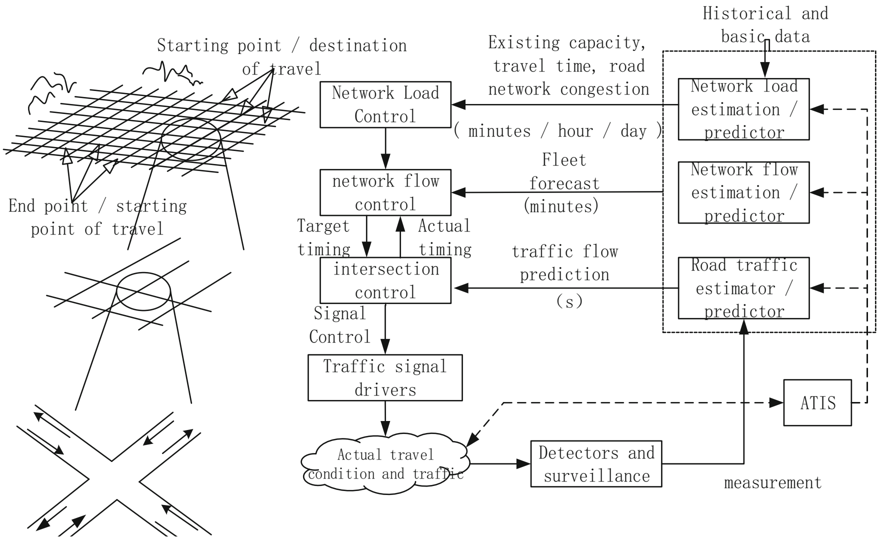


Fig. 7.19 Hierarchical structure of RHODES system [4]

Control Method of RHODES System

The RHODES system tracks the fluctuation of traffic flow in a short period of time and the change trend of traffic flow in a long period of time by predicting the arrival of a single vehicle and the movement of the vehicle fleet. According to the principle of optimizing the given performance index (minimum average delay, minimum average queue length at the intersection or minimum number of stops), the phase is divided, and a non-parametric control model is proposed. In other words, the signal timing scheme is not formulated by using parameters such as period, phase difference and green signal ratio, but by using phase sequence and phase length.

Intersection Control

The intersection control layer proposes a concept of phase controllable optimization (COP). According to the predicted value of arriving vehicles, the dynamic programming (DP) method is used to find the optimal phase sequence and phase length, so that the given performance index can reach the optimal, and the phase sequence can also be a pre-given fixed sequence. In order to apply dynamic programming in real time, the RHODES system uses a sliding time window to reduce the amount of calculation, and uses a dynamic programming algorithm to optimize the phase sequence and phase length. Before optimization, the phase sequence should be given (which can be given by the network flow control of the upper layer), so that each phase corresponds to a phase, and the number of phases is generally greater than the number of phases, which may be the same phase corresponds to different stages. If the traffic engineer has no restriction, it is allowed to skip the phase by setting a certain phase length to 0, so as to achieve the purpose of optimizing the phase sequence. The COP is carried out in a sliding time window of 45 ~ 60 s. Each possible decision in each stage is evaluated in a forward recursive manner, and then the backward recursive decision is made to minimize the phase sequence and phase length of the system performance index in the optimal sliding time window. The decision in the first stage is implemented. Then, before the current phase is about to end, the next optimization will begin with the current phase based on recent observations and projections. COP can use different performance indicators (including delays, queue length, and number of stops) to make the control algorithm more flexible.

Network Flow Control

The network flow control layer proposes an algorithm called real-time green band (Realband). Its principle is based on the current fleet forecast and comprehensively consider the possible conflicts of the fleet in all directions of the network, and use the decision tree method to control the network. The traffic signal is coordinated and optimized, and a traveling green wave band is generated. Its width and speed value can optimize the network objective function, that is, the number of delays and stops is the least. When the RHODES system predicts that there is a conflict between the green signal demands of two or more fleets, it first generates a decision tree, and each branch of the decision tree represents a conflict resolution strategy. Use the corresponding model to evaluate each strategy, and select the strategy with the best performance as the control strategy of the network control layer. The control decision of the network layer is used to establish coordination constraints for the intersection control layer.

The real-time green band algorithm combines the advantages of the coordinated control system based on the delay model (such as SCOOT) and the coordinated control system based on the bandwidth model (such as SCATS), takes full account of the continuity of the vehicle fleet in all directions, and generates the green band online according to the predicted value of the arrival time, size and speed of the vehicle fleet, as well as the degree of dispersion or compression and the interference of the steering vehicle flow, so as to ensure the continuity of the vehicle fleet as much as possible and optimize the system performance index.

Realband identifies the fleet and predicts its movement in the network (including the time to reach the intersection, the size and speed of the fleet) by filtering and fusing the traffic flow data obtained from different information sources in recent minutes, and then uses the APPES-NET model to evolve the predicted movement of the fleet through the network within a given time window. Traffic signals provide a suitable green time for the predicted fleet to optimize the given performance indicators. If there is a conflict between the two teams arriving at the intersection at the same time on the demand for green signals, one of the teams is given priority to the right of passage or one of the teams is divided into two parts, so that the given performance index is optimal. The main goal of Realband is to resolve the conflict between the vehicle groups’ demands for green signals.

Characteristics of RHODES System

The RHODES system has the following characteristics.

1. RHODES is a two-level structure in hardware, namely the central computer level and signal controller level. But the control structure adopts a three-tier hierarchical structure, namely the intersection control layer, network control layer, and network load distribution layer. The intersection control layer tracks the fluctuation of traffic flow in a short period of time (45–60 s) for intersection traffic control. The network control layer tracks the change trend of traffic flow in a long time (200–300 s) to establish coordination constraints between intersections. The network load distribution layer tracks the long-term traffic flow variation and provides interfaces with other modules of the intelligent transportation system.
2. Proposed a new coordinated real-time adaptive control strategy between intersections: "Real-time green band." According to the current fleet forecast value, comprehensively consider the possible conflicts of the fleet in various directions on the network, use the decision tree method to optimize the network, and generate the traveling green wave belt in real time. Its width and speed value can optimize the regional objective function, that is, delay and the least number of stops.
3. Install the vehicle detector at the vehicle entrance of the intersection to detect the traffic flow in the three directions (turn left, turn right, and go straight) at the upstream intersection. The detection results can be used for downstream predictions as well as the original predictions at the entrance. Verification and correction of results.
4. A concept of controllable phase optimization is proposed. According to the predicted value of arriving vehicle, the optimal phase sequence and phase length are found by dynamic programming method. In order to apply dynamic programming in real time, the system adopts sliding time window to improve the accuracy of control.
5. The system optimization objective can be to minimize the average vehicle delay, the average queue length at the intersection or the number of parking. Flexible and diverse system objectives make the control algorithm more flexible.
6. The interface with traffic analysis software is provided, which can offline evaluate the advantages and disadvantages of timing schemes or be used as a research tool.

7.3.2.4 SPOT/UTOPIA System

SPOT/UTOPIA system is a distributed real-time traffic control system developed by Mizar Automazione in Italy. The earliest version was installed in Turin, Italy, in 1985 and achieved satisfactory results. The SPOT/UTOPIA system consists of two parts, SPOT (local) and UTOPIA (region), and its structure is shown in Fig. 7.20. UTOPIA is a relatively advanced area control, which optimizes the use of a macro-traffic model based on historical data. SPOT completes the local optimization work,

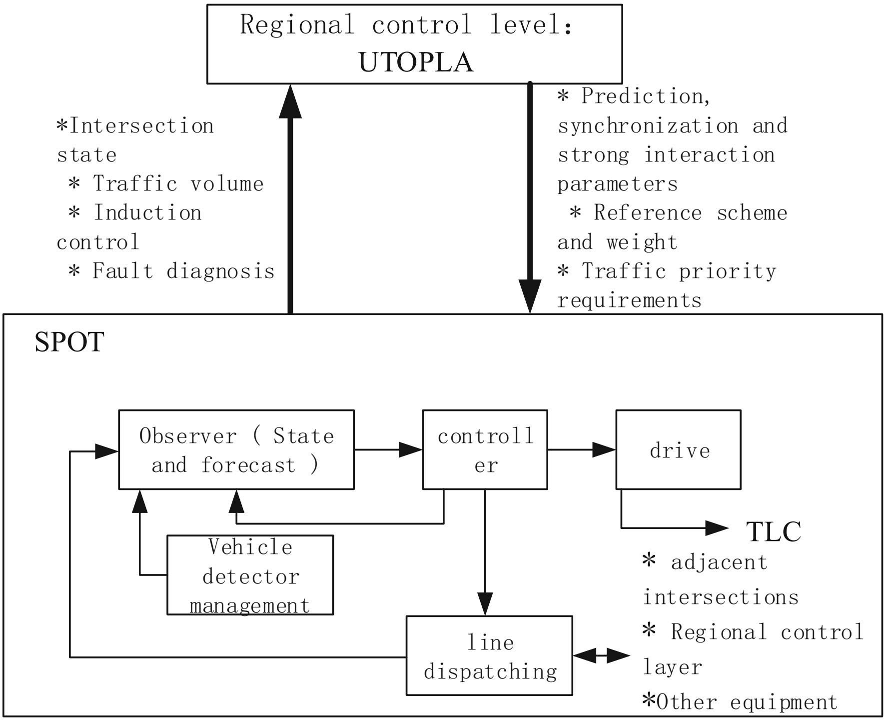


Fig. 7.20 SPOT/UTOPIA system architecture [6]

uses the micro model on each traffic control machine, and uses the data from the local control machine and the area model to optimize a single intersection. The system adopts the concept of "strong interaction" to ensure the optimality and robustness of the area control.

SPOT System

When SPOT works independently, it is a small distributed traffic control system, and there are generally no more than six intersections managed by SPOT system. There is no need to install the central computer when it is used below six intersections. When the system is large, the UTOPIA central computer control system needs to be added. Each intersection machine must install a SPOT unit, which can communicate with the traffic light controller and other intersection machines, so the communication mode of each intersection is equivalent.

At each intersection, SPOT seeks to use the minimum total cost function. This "cost" function mainly considers delays, number of stops, remaining capacity, area control strategies recommended by superior control, priority of public transportation and special vehicles, pedestrian crossing requests, and other special circumstances.

SPOT continuously repeats and adjusts to minimize the intersection cost function. In each calculation cycle, all SPOT units exchange information about traffic status and priority strategies with their neighboring SPOT units. The optimization goal is to ensure that the total travel time of the private car is the shortest under the premise that the bus does not encounter the red light, so the maximum weight is given to the lost time item of the bus at the intersection.

SPOT has two control principles when optimizing, prediction (each SPOT unit receives real-time arrival prediction from upstream intersections) and strong interaction (in local optimization, each control unit considers the negative impact it may bring to the downstream intersection). Adjacent intersections exchange data every 3 s, and at the same time, each intersection signal controller performs an optimization on the sliding time window. The length of the time window is 2 min, which means that the result of each optimization can only run for 3 s. When necessary, the regional control machine UTOPIA can participate in the adjustment of traffic demand forecasts and modify local parameters.

Both SPOT and UTOPIA have a complete set of operational rules for estimating traffic demand and traffic model parameters. In SPOT, the queue length is estimated every 3 s, and the turn ratio and road capacity are improved every cycle. There is also a congestion detection model, which greatly reduces the system adjustment and repeated time.

SPOT can provide good adaptive control for all traffic conditions, and it can play a greater role when traffic flow has large, sudden and unpredictable changes. Without sacrificing adaptive performance, SPOT can give absolute priority to bus or other special vehicles.

The SPOT unit does not directly control the signal lamp, but controls the traffic signal controller, and obtains sensor data from the traffic signal controller or directly from the vehicle detector. SPOT control unit can also be connected with beacon controller of variable information flag and navigation system.

The SPOT unit is connected to a LAN, and the communication structure can be radial, raster, or layered. Each SPOT unit is a node of the network and has complete message link capability. Therefore, any SPOT unit can transmit information to the appropriate terminal, which greatly reduces the installation and maintenance costs and enhances the robustness of the system.

UTOPIA System

UTOPIA uses a central computer in a network to run. UTOPIA calculates an optimized control strategy for each subarea in the network, and each subarea has a common cycle length. UTOPIA provides an event scheduler and a conversion model, which can provide TCP/IP protocol interfaces for other systems. During operation, the system maintains a historical database, including regular flow, turning ratio, saturated flow, and life cycle. UTOPIA also maintains a statistical database, mainly for specific statistical calculations on historical databases.

UTOPIA provides the following features:

1. Equipment diagnosis: Real-time monitoring of the status of intersection equipment (traffic light controller, roadside units, detectors, communication lines, other peripherals).
2. Traffic data detection: Continuous real-time monitoring of traffic data in the control area (cycle length, queue length, saturation flow rate, traffic flow, and turn ratio) and regular updates.
3. Performance monitoring: Monitor system performance in real time through validity index and failure indicator of intersection equipment.
4. Historical data analysis: The files about the measured and estimated traffic data and diagnostic information are automatically managed, including the analysis detection data, visualization of historical data, and comparison of historical data with current data.
5. Generation and transmission of regular reports: Through e-mail regular transmission of statistical reports on system and equipment functions, the form, and configuration of reports can be customized by users.
6. Automatic alarm generation: The alarm can be automatically generated by SMS (Short Message Service) and e-mail. Alarm generation can be customized in the following aspects—the selection of crossroads related to alarm, the definition of alarm threshold for selected equipment and parameters, the selection of alarm types for each recipient, the number of alarm receivers and e-mail addresses.
7. Service management: This function allows permission setting for other personnel.
8. Provide simulation environment for planning: Online network simulation tools can compare and analyze different scenarios. System control and UTOPIA can be simulated to evaluate the impact of UTOPIA installation or the impact on existing system improvements.
9. Flexible interaction with the system: While monitoring system and machine performance, authorized users can directly set functional parameters and send commands to UTOPIA system. According to the architecture of UTOPIA, the crossroad controller interacts with the adjacent crossroad controller and intersects with the regional control reference strategy calculated by the central system mutual, so as to control the signal intersection.

Characteristics of SPOT/UTOPIA System

SPOT/UTOPIA system has the following characteristics:

1. The function of bus priority is considered in the design and development of the system, so its control goal is to ensure that the bus does not encounter red light as far as possible, so that the total travel time of private cars is the shortest. In order to achieve this goal, the system introduces the concept of weight in minimizing the objective function, and the maximum weight gives the bus loss time term at the intersection.

2. In order to ensure the optimality and robustness of subarea control, the system adopts the concept of strong interaction, that is, the objective function of this intersection should consider the state of adjacent intersections and the constraints given by the regional control level.
3. UTOPIA is to make optimal control decisions for the whole network. It receives the intersection state information from each SPOT unit, determines the division of subregions, the optimal period of subregions (each subregion runs under the same period), and the optimal weight. In addition to communicating with SPOT, the system can also exchange information with a higher layer of system (such as traffic command center) through TCP/IP interface. UTOPIA also established a database of actual state information during operation, so that backup scheme selection can be carried out when real-time system faults occur.

7.4 Application and Development Trend of Intelligent Traffic Control System in China

The research on traffic signal control system in China started late. In the late 1970s, Beijing adopted DJS-130 computer to study the coordination control of arterial lines. Since the 1980s, on the one hand, the state has adopted the policy of combining introduction and development to establish some urban road traffic control systems. On the other hand, investment in urban traffic signal control technology research and development to adapt to China's mixed traffic as the main characteristics of intelligent traffic control system. Such as Beijing introduced SCOOT system, Shanghai introduced SCATS system. Shenyang Institute of Automation, Chinese Academy of Sciences, built and implemented the first urban traffic adaptive control system in Dalian. The Ministry of Communications, the Ministry of Public Security and Nanjing completed the "Seventh Five-Year" Nanjing urban traffic control system, the key project, has laid a good foundation for the development of traffic signal control system in China. At present, China's city annual increase and update of urban traffic signal control intersections are in ten thousand scale, the emergence of Wuxi Huatong, Nanjing Rice, Beijing Yihualu, Zhejiang University Central Control, Shanghai Baokang, Lianyungang Jerry, Shanghai Electric Jun Code, Nanjing Toronto, Nanjing Luopu, Zhejiang Dahua, and other mainstream signal control manufacturers. At the same time, China has gradually formed some representative traffic signal control systems, such as Nanjing Rice urban traffic control system, Qingdao HiCon traffic signal control system, Shenzhen Greenway SMOOTH traffic signal control system, etc. In China urban road traffic management and control plays an increasingly important role.

7.4.1 Nanjing Rice Urban Traffic Control System

Nanjing Rice Urban Traffic Control System (NUTCS) is the first real-time adaptive urban traffic signal control system developed by China. With the approval of the former National Planning Commission and the National Science and Technology Commission, NUTCS was jointly developed by the Institute of Traffic Management Science of the Ministry of Public Security, Tongji University, 28 Institutes of the Ministry of Electronics (now the 28th Institute of China Electronics Technology Group Co., Ltd.) and Nanjing Traffic Police. It is a key national science and technology research project (No. 2443) in the "Seventh Five-Year Plan" and has won many technical awards from the Ministry of Public Security and the state.

NUTCS combines the advantages of SCOOT and SCATS to meet and adapt to the domestic road network density with low density and wide intersection spacing and the outstanding traffic characteristics of mixed traffic. It can automatically coordinate and control the traffic signal timing plan in the area, and balance the traffic flow of the road network. Operation to minimize the number of stops, delays and environmental pollution, and give full play to the traffic benefits of the road system. Usually, the two-level control structure at the intersection level and the regional level can be expanded to the three-level distributed hierarchical control structure at the intersection level, the regional level and the central level if necessary. The system set up real-time adaptive, fixed timing and no cable linkage control three modes, with security, fire protection, ambulance, bus signal, and manual designated functions. When necessary, manual intervention can be used to directly control the intersection signal to execute the designated phase to ensure the smooth flow of urban road traffic and the priority passage of special vehicles. The working mode is flexible and the function is complete.

In order to further study the signal control system adapted to the characteristics of urban traffic flow in China, Nanjing Rice Large Electronic Systems Engineering Co. Ltd. was established in July 1988 by the 28th Institute of China Electronic Science and Technology Group Corporation. Nanjing Rice independently developed the first generation of signal machine technology through years of efforts. After the first set of networking signal machines suitable for China's national conditions was put into the market, it was first popularized and applied in Zhuzhou City, Hunan Province, effectively improving the local traffic congestion, reducing the intensity of traffic police work, and obtaining user recognition.

In 2014, Nanjing launched the construction of urban traffic signal machine networking and bus signal priority control system. During the Nanjing Youth Olympic Games, Nanjing Rice made important contributions to traffic security and special service tasks, and ensured the traffic safety of the National Public Sacrifice Day on December 13. After the bus signal priority system is completed, the average speed of the bus increases by 15%, and the bus is the number of parking is reduced by 30%, which creates great social and economic benefits. At the same time, Nanjing has strengthened the signal coordination and control, and built 154 green wave belts and 1063 intersections. Among them, 41 tidal green wave belts and 287 intersections have been built. The urban green wave signal control rate reaches 80%, which effectively improves the urban traffic efficiency.

In 2017, Nanjing Rice developed an intelligent control system of urban road network signal based on holographic detection. The “spatiotemporal three-section holographic collection” mode was applied to obtain the queuing information of vehicles on the import road in space, as well as the passing information of vehicles on the stop line, the middle part of the channel, and the end of the channel. The traffic demand of each direction of the green light at the beginning, the middle, and the end of the green light was analyzed in time. The multidimensional spatiotemporal information was deeply integrated to master the law of vehicle arrival and departure, and the formation and dissipation of queuing. At the same time, the advanced solutions of holographic control are proposed for single intersection and arterial road, which can minimize the delay of intersection control, eliminate the phenomenon of green light in flat peak, balance the queue of each flow in peak, and ensure the coordinated control of green wave at upstream and downstream intersections. The system has been applied in Taishan Road and Huangshan Road of Hexi Street in Nanjing. According to statistics, in the full intelligent control mode, the signal light in the flat peak period to reduce empty waiting, peak period to reduce queuing reflects a more obvious advantage.

After promoting the use of Rice road traffic signal control system and signal products, Nanjing has obtained the first-class management level city title of “unimpeded project” for nine consecutive times. At present, there are more than 1500 intersections in Nanjing using Rice traffic signal control machine to manage the intersection traffic signal. More than 150 roads in the urban area have realized green wave control, and the green wave signal control rate is 80%. At present, Nanjing Rice’s traffic signal control system has developed to the third generation of products, mainly distributed in Nanjing, Zhuzhou, Changshu, Foshan, Qinhuangdao, and other 120 domestic large and medium-sized cities, and has been extended to Kenya, Pakistan, and Cote d’Ivoire and other overseas countries.

7.4.2 Qingdao Haixin HiCon Traffic Signal Control System

HiCon adaptive traffic signal control system is an intelligent transportation solution developed by Qingdao Haixin Network Technology Co., Ltd., including HSC-100 series traffic signal machine, HiCon traffic signal control system software, and CMT traffic signal machine configuration and maintenance tool software. According to the current situation of mixed traffic, HiCon system establishes a machine-non-mixed control model to control mixed traffic flow. The multilevel distributed control structure is divided into control platform layer, control center layer, communication layer and intersection layer. The system has a complete algorithm system, including regional coordination control algorithm, inductive coordination control algorithm, pedestrian secondary crossing algorithm, coordinated control algorithm of urban rapid access and urban intersection, and emergency detection algorithm. It supports NTCIP open protocol and meets the latest national standards.

In 2002, about 50 development staff of Haixin Network Technology Co., Ltd. took more than 3 years. According to the characteristics of China's transportation, a centralized coordinated signal machine-HSC-100 signal machine was developed. At the end of 2003, the maritime communication network technology successfully won the bid of Qingdao Huangdao District and Longkou City traffic signal control system, which opened the prelude of the maritime traffic signal control system entering the market. In December 2005, HiCon adaptive traffic signal control system won the bid of Beijing intelligent traffic management investment construction project, completely breaking the monopoly situation of foreign companies in high-end signal controller, which is a milestone in the history of China's traffic signal control development. At the beginning of 2006, Haixin again won the bid for the construction project of Beijing expressway traffic signal control system, which played a good role in promoting the comprehensive improvement of Beijing traffic conditions. Its system characteristics are as follows, using NTCIP communication protocol, the system is complete, and has good versatility and compatibility. Efficient, reliable, and open communication subsystem ensures the reliability of internal real-time communication performance, efficiency, scalability. At the same time, the openness of the system is truly realized. The system interface is transparent, providing secondary development capabilities and facilitating the integration of multiple systems. The system has good fault diagnosis function, can display the fault condition of the intersection equipment in real time, and can realize the remote maintenance function of the signal machine through the network. The system adopts a real-time optimization algorithm combining scheme selection and scheme generation, and uses advanced prediction and degradation technology to greatly reduce the dependence of the system on the detector. Traffic signal machine CPU uses 32-bit chip, control function is strong.

The winning bid of Beijing Olympic Games and Beijing expressway traffic signal control system project makes the sea signal machine gradually move toward the national market. After a long period of accumulation, the signal machines of HITIC network technology have been distributed throughout the country, and are the third largest international signal control system widely used after SCATS and SCOOT.

In 2014, the HiCon traffic signal control system was applied to the Qingdao World Garden surrounding road intelligent traffic management service system project, Jinan City traffic police detachment traffic signal upgrade project, Foshan Chancheng upgrade traffic signal lamp project, Jiangmen City Pengjiang and Jianghai two district public security intelligent traffic management system phase II construction project. In 2015, the system was applied to the traffic signal control system construction project of Jinan traffic police detachment, the intelligent transportation phase III project of Shouguang City, the intelligent transportation system construction project of Heshan City, the intelligent transportation system construction project of Taishan City, the traffic signal control system upgrading project of Nanchang Traffic Administration Bureau, and the intelligent transportation control and guidance system project of Baoding central city. The intelligent traffic management system of Wuhan Donghu New Technology Development Zone—the upgrading and transformation project of regional traffic signal control system, and the intelligent application demonstration project of Xining urban public transport.

At present, Haixin has installed traffic signal control system for more than 80 cities in the domestic market, including Beijing, Qingdao, Jinan, Wuhan, Fuzhou, Xiamen, Guiyang, Lanzhou, Taiyuan, Yinchuan, Nanchang, Changsha, Urumqi, Xining, Changchun, Nanchang, Guilin, Foshan, Jiangmen, Zibo, Yantai, Zhenjiang, Suzhou and other large and medium-sized cities. The successful cases of HiCon adaptive traffic signal control system application are mainly in Taiyuan, Nanchang, Changchun, Fuzhou, Xiamen, Suzhou, Huzhou, Zibo, Heze and other cities.

7.4.3 Shenzhen SMOOTH Traffic Signal Control System

Shenzhen regional traffic signal control system was established in 1989. Around 1999, in view of Shenzhen high saturation, high complexity, high expectations of traffic status and regularity, variability, random combination of traffic characteristics, Shenzhen traffic police proposed the development of SMOOTH traffic signal control system needs. SMOOTH system was developed in early 1999. In the middle of 2001, the prototype of signal machine and coil vehicle detector was put into trial and operated induction control. At the end of 2002, the system platform on-line trial operation, to achieve green wave control and other functions, the first use of GPRS wireless networking. At the end of 2003, the signal machine and vehicle detector were upgraded to embedded platform to realize adaptive control and bus priority control, and the system function tends to be perfect.

Subsequently, Shenzhen began to promote the use of SMOOTH system in 2003. In 2007, the system realized the release overflow specific energy such as bottleneck control and close-distance intersection group control. In 2009, the application of full-range countdown in adaptive control was realized, with 105 adaptive control intersections and 38 inductive control intersections. In recent years, mainly through the green wave control benefits, green wave control over the intersection of more than 76%.

SMOOTH traffic signal control system adopts distributed control mode, three-tier architecture, large database, multi-server collaborative processing. According to the traffic demand and traffic characteristics of Shenzhen, a flexible and effective control strategy is adopted to maximize traffic capacity and minimize congestion during peak hours. In the development process of SMOOTH system, Japan's KATNET system, the UK's SCOOT system, Australia's SCATS system, and other systems that were most widely used in the world at that time were studied and analyzed, aiming at fully drawing on the advantages of famous systems, abandoning limitations and taking the road of technological innovation. The SMOOTH system inherits the method of KATNET system to identify traffic state, draws on the strategy of SCOOT system proximity prediction, and introduces the means of SCATS system tactical fine-tuning. In view of the current situation and development trend of traffic in China, a multi-objective decision-making control strategy based on traffic state recognition and a comprehensive solution combining single intersection adaptive control and road network regional coordination control are proposed.

The SMOOTH system has the characteristics of highly intelligent automatic control It can adjust the phase and timing of signal control at any time according to the change of traffic flow, so as to maximize the improvement of intersection capacity and reduce the queuing and delay of motor vehicles. In addition, the system also has the characteristics of wide control range, central and intersection wireless networking, good scalability and openness, high stability and strong anti-interference ability.

SMOOTH system is mainly used in the following aspects, variable lane and variable signal lamp control, countdown indication, pedestrian crossing demand sensing, signal control via left turn, decision support of tidal lane signal control system, compared with the Internet big data integration, and realize signal tuning and timing optimization.

The SMOOTH system is mainly used in Shenzhen and Kunming. At present, the SMOOTH system in Shenzhen has a total of about 2800 intersections. There are 235 single-machine operation intersections, and more than 2500 networked control intersections. Wireless networking is mainly used. There are more than 4000 registered devices for vehicle detectors, and more than 500 intersections in Shenzhen's history have achieved adaptive control of intersections during the peak period of application. The application results show that the system meets the design goals and application requirements, effectively reduces the traffic delay of the road network, improves the capacity, and significantly improves the traffic jam. In addition, the SMOOTH system integrates with the application brain of the Shenzhen traffic police, and realizes the self-selection of the whole process of traffic flow perception and control mode based on the data perception of Shenzhen traffic brain and the computing power of artificial intelligence.

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