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Construction of Smart Transportation City System Based on Digital Twins

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Abstract. With the acceleration of urbanization, traffic congestion has become an important factor affecting urban economic development and the quality of life of residents. How to use technological means to improve the transportation system has become an important task in the construction of smart cities. The emergence of digital twin technology provides a shortcut for the development of smart cities. As a current research hotspot, the construction of smart transportation city systems based on digital twins aims to improve traffic efficiency, reduce traffic congestion, enhance urban traffic safety, and provide personalized strategies through intelligent and data-driven methods, thereby improving the travel experience of urban residents. This paper adopts a comprehensive research method, combining literature review, empirical analysis, and case study, to deeply explore the smart transportation city system based on digital twins. At the same time, advanced technological means such as perception devices, data collection technology, digital twin simulation technology, and intelligent analysis algorithms are also utilized to effectively simulate and restore complex traffic scenes, monitor and analyze urban traffic data in real-time, and provide scientific basis for traffic management and decision-making. Build an efficient and intelligent urban transportation system through the integration of a series of technologies and methods. The research results indicate that the application of digital twin technology can achieve comprehensive perception, accurate simulation, and intelligent regulation of urban transportation systems. This not only helps to solve traffic congestion problems, improve transportation efficiency, but also enhances the travel experience of urban residents.

Keywords. Digital twin, Smart transportation, Smart cities, System construction

1. Introduction

With the acceleration of global urbanization, traffic congestion has increasingly become a bottleneck in urban development. Traditional transportation management methods can no longer meet the needs of modern cities. Since the National "14th Five Year Plan" in 2021 clearly proposed "exploring the construction of digital twin cities", various departments have successively introduced supportive policies. The State Council has issued the "14th Five Year Plan for Digital Economy Development", proposing "building digital twin cities according to local conditions" and so on [1]. Smart

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transportation, as a new urban development model, provides new ideas for solving urban transportation problems by utilizing advanced technologies such as information technology, big data, the Internet of Things, artificial intelligence, and digital twins[2]. The most prominent digital twin technology, as an important technological means in the era of the Internet of Things and big data, can turn 3D models into information sources related to urban environment and landscape, achieve virtual mapping and accurate simulation of the real world, become the foundation for managing smart cities[3], and provide new ideas and methods for solving urban transportation problems. The use of digital twin technology to construct a city in virtual cyberspace that corresponds to the physical world has shown people the embryonic form of future smart transportation cities[4]. However, there are still many problems regarding the seamless interaction between smart transportation cities as digital models and physical cities. At present, the development of digital twin smart transportation cities is still stuck in the integration of GIS and BIM, used for displaying cities on web and mobile platforms, and used for intelligent analysis and making real-time plan adjustments based on real-time traffic data[5]. There is still little room for further research and promotion. The construction and application of smart transportation systems still face many challenges and problems. How to achieve standardization and scaling of smart transportation systems Sustainable development, improving system stability and security[6], is still the focus and difficulty of current research. In response to the above issues, this study will adopt a comprehensive research method, combined with empirical analysis and case studies, to deeply explore the construction of a smart transportation city system based on digital twins. The aim is to build a standardized, scaled, efficient, intelligent, and sustainable smart transportation city system, improve transportation efficiency, and enhance the happiness index of residents.

2. Key Technologies and Methods

The following advanced technologies will be used in the construction of smart transportation city systems:

2.1. Big Data Technology

The technology architecture of smart transportation cities involves a large amount of data collection, storage, processing, mining, and analysis. The distributed data storage and processing of big data technology can help store and quickly process massive amounts of data, improve processing efficiency, and discover hidden patterns and trends in the data, thereby providing scientific basis for decision-making and strong support for urban traffic management and optimization.

2.2. Sensor Technology

By using various sensor devices, accurate traffic information can be obtained in real-time, including vehicle flow, speed, road conditions, weather conditions, etc. These pieces of information are of great significance for urban traffic management and optimization, and can provide real-time data support for smart city transportation systems.

2.3. Intelligent Algorithms

Intelligent algorithms play a crucial role in data processing, pattern recognition, prediction, and optimization. By using intelligent algorithms, rapid processing, accurate prediction, and intelligent decision-making of traffic data can be achieved, improving the operational efficiency, safety, and user experience of transportation systems. Through algorithmic methods such as machine learning and model optimization, automatic adjustment of traffic signals, prediction and optimization control of traffic flow can be achieved.

2.4. Cloud Computing Technology

Cloud computing technology can centralize computing and storage resources into a virtual cloud environment through virtualization of resources, achieving dynamic management and scheduling of resources. This not only improves the speed and efficiency of data processing, but also ensures the security and integrity of data. Cloud computing technology can achieve data backup and recovery through load balancing, fault tolerance and other technical means, ensuring the reliability and stability of information processing[7]. Cloud computing technology provides strong support for the development of smart transportation city systems.

2.5. Data Twin Technology

Digital twin technology is a simulation technology that models physical entities through digital means and realizes the process of interaction, mapping, and connection with physical entities in a digital environment. Digital twin is a concept that transcends reality and can be seen as a digital mapping system for one or more important and interdependent equipment systems[8]. The core of digital twin technology lies in establishing a digital model that can accurately reflect the state, behavior, and performance of physical entities. The digital model can be continuously updated and corrected through data collected by sensors to reflect changes in physical entities. In addition, digital twin technology also provides the ability to predict, analyze, and optimize physical entities, helping to achieve intelligent operations and maintenance.

2.6. Virtual Simulation Technology

Virtual simulation technology, also known as virtual reality technology or simulation technology, is a technology that uses computer technology to simulate real systems or scenes. It establishes a virtual environment that allows users to interact with and experience similar to the real world [9]. It can help people better understand complex systems, optimize design, improve security, reduce costs, etc.

3. Architecture Design of Smart Transportation City System

The overall smart transportation city system can adopt a five layer architecture with five subsystems: IoT perception layer, network layer, information support layer, business application layer, and presentation application layer, forming five subsystems:

perception subsystem, control subsystem, management subsystem, service subsystem, and data subsystem. The composition and functions of each subsystem are shown in Figure 1:

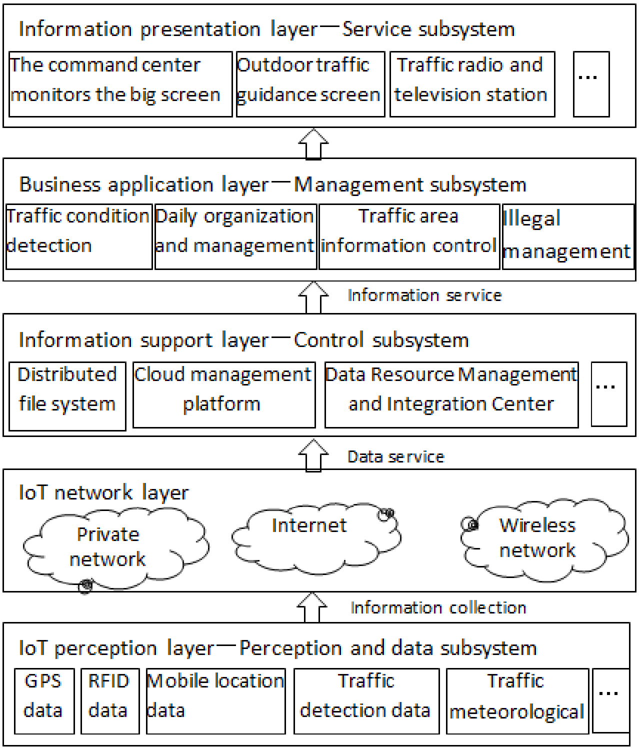

Figure 1. Architecture design and subsystem division diagram of smart transportation city system

3.1. Smart Transportation City Perception Subsystem

The intelligent traffic perception subsystem obtains traffic information through sensor technology, and comprehensively and real-time obtains various traffic information, including key indicators such as traffic flow, speed, density, as well as environmental and vehicle information, through comprehensive technical algorithms such as image processing algorithms, sensor fusion algorithms, machine learning algorithms, artificial intelligence algorithms, data integration and exchange algorithms. The control center conducts global scheduling and decision-making based on this information to achieve more efficient and safe traffic management[10]. For example, when a traffic accident or congestion occurs on a certain section of the road, the control center can quickly adjust the control strategy of the signal lights, guide vehicles to detour or conduct emergency rescue.

3.2. Smart Transportation City Control Subsystem

The intelligent traffic control subsystem is a core component of the intelligent transportation system. It mainly relies on a large amount of real-time data provided by the intelligent traffic perception subsystem, which is deeply analyzed and processed through advanced intelligent algorithms to achieve optimized traffic signal regulation[11]. Being able to dynamically adjust the time interval of signal lights based on real-time traffic flow, speed, density and other data, in order to better match traffic demand, guide traffic flow reasonably, effectively alleviate congestion and improve road traffic efficiency[12]. This subsystem can further automatically adjust the traffic strategy of the road network based on information such as traffic flow and congestion, and improve the utilization rate of the road network.

For example, based on historical traffic data, a linear regression model is used to predict the relationship between waiting time and signal timing scheme. Combined with dynamic real-time traffic flow, speed, density and other traffic data, the "Adaptive Traffic Control System Based on Historical and Real Time Data" method is used to provide an automatic adjustment signal timing scheme, as shown in Algorithm 1:

Algorithm 1: Automatically adjust the timing scheme of signal lights

```
import pandas as pd
import numpy as np
from sklearn.linear_model import LinearRegression
class SignalController:
def_init(self, historical_data):
# Store historical traffic data
self.historical_data = historical_data
# Store real-time traffic data, e.g., traffic volume, speed, density, etc.
self.realtime_data = []
# Store the time intervals for each traffic signal
self.signal_times = {}
# Store the last adjustment time for each signal light
self.previous_times = {}
def update_realtime_data(self, data):
"""Update real-time traffic data"""
self.realtime_data.append(data)
def adjust_signal_times(self):
"""Adjust signal light time intervals based on historical and real-time traffic data"""
# Assume we have a function to calculate the new time interval based on historical and real-time traffic data
def calculate_new_time(historical_data, realtime_data):
# Implement the calculation logic according to actual requirements
pass
# Iterate through all signal lights
for signal_light in self.signal_times:
# Get the last adjustment time for the signal light
last_adjustment = self.previous_times.get(signal_light, None)
if last_adjustment:
# If the last adjustment time exists, calculate the elapsed time
elapsed_time = datetime.now() - last_adjustment
# Get historical and real-time traffic data for the signal light
historical_data = self.historical_data.get(signal_light, [])
current_data = self.realtime_data[-1] if self.realtime_data else None
# Calculate the new time interval
new_time = calculate_new_time(historical_data, current_data)
# Update the signal light's time interval
self.signal_times[signal_light] = new_time - elapsed_time
else:
# If the last adjustment time does not exist, use a default time interval or calculate it accordingly
pass
# Update the last adjustment time for each signal light
for signal_light in self.signal_times:
self.previous_times[signal_light] = datetime.now()
```

In this algorithm, the SignalController class is responsible for managing historical traffic data, real-time traffic data, and time intervals for traffic lights. The update_realtime_data method is used to update real-time traffic data, while the adjust_signal_times method is used to adjust the time interval of traffic lights based on historical and real-time traffic data. This method will traverse all traffic lights and calculate new time intervals as needed. Finally, it will update the time interval of each traffic light and record the last adjustment time.

This system can use historical data to learn traffic patterns and adjust the timing scheme of traffic lights based on real-time data. Of course, in practical applications, more complex models may be needed to consider more influencing factors, such as traffic flow, road design, weather conditions, etc.

3.3. Smart Transportation City Management Subsystem

The intelligent transportation management subsystem plays a core role in the architecture of intelligent transportation technology. It is responsible for collecting, analyzing, and processing a large amount of traffic information. Through this data, the system can monitor traffic conditions in real time, predict future traffic flow trends through intelligent algorithms, accurately identify traffic bottlenecks, and develop reasonable road diversion plans to reduce traffic pressure in congested areas[13]. This subsystem is also responsible for predicting and handling traffic accidents, providing a real-time traffic condition query system, and reminding drivers to choose the optimal travel plan[14].

We can use machine learning algorithms such as time series prediction and clustering analysis, and then use Python algorithms to predict future traffic flow trends and identify traffic bottlenecks:

Algorithm 2: Predict future traffic flow trends and identify traffic bottlenecks

```
import pandas as pd
from sklearn.cluster import KMeans
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import mean_squared_error
from sklearn.model_selection import train_test_split
# Load historical traffic data
data = pd.read_csv('traffic_data.csv')
# Feature engineering: Select features related to traffic volume
features = data[['traffic_volume', 'average_speed', 'density']].values
# Standardize features
scaler = StandardScaler()
features = scaler.fit_transform(features)
# Split data into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(features, data['traffic_volume'], test_size=0.2, random_state=42)
# Perform KMeans clustering on the training data to identify traffic bottlenecks
kmeans = KMeans(n_clusters=3)  # Assume there are 3 traffic bottlenecks
kmeans.fit(X_train)
labels = kmeans.predict(X_train)
# Divide the training data into 3 groups representing different bottleneck regions based on the clustering results
traffic_bottleneck_1 = X_train[labels == 0]
traffic_bottleneck_2 = X_train[labels == 1]
traffic_bottleneck_3 = X_train[labels == 2]
# Predict future traffic trends for each bottleneck region using a time series prediction algorithm (e.g., ARIMA or LSTM)
from statsmodels.tsa.arima.model import ARIMA
# Assume using ARIMA(5,1,0) model for prediction
model = ARIMA(y_train, order=(5,1,0))
model_fit = model.fit()
forecast = model_fit.forecast(steps=365)   # Predict traffic trends for the next year
```

In this algorithm, we first use the Pandas library to load historical traffic data and select features related to traffic flow. Then, we use the KMeans algorithm from the Sklearn library to perform clustering analysis on the training data and identify traffic bottleneck areas. Next, we will use the ARIMA model to predict the future flow trends of each traffic bottleneck area. Finally, based on the predicted results, we can develop corresponding road diversion plans, Formulate corresponding diversion plans for each bottleneck region, such as adding exits or restricting entry.

Of course, in the actual prediction and diversion plan formulation process, we also need to consider more factors, such as different time periods, weather conditions, road conditions, and many other integrated systems.

3.4. Smart Transportation City Service Subsystem

The intelligent transportation service subsystem is an important component of the intelligent transportation technology architecture. By providing personalized services such as real-time road condition inquiry, parking space inquiry, public transportation inquiry, etc[15].it realizes deep integration and efficient processing of traffic information, and meets different travel needs of users through various methods such as mobile apps, public information display screens, voice navigation[16], etc. This not only improves the transportation efficiency of the city, but also helps to improve the travel experience of citizens and promote the sustainable development of smart cities.

3.5. Smart Transportation City Data Subsystem

The intelligent transportation data subsystem provides important support for transportation decision-making through its powerful data storage, management, and analysis capabilities, and provides a solid data foundation for the continuous optimization of intelligent transportation technology[17]. By adopting a distributed storage architecture, the system can address the challenges of storing massive amounts of data, ensure high-speed reading and writing of data, and achieve data classification, indexing, and querying, providing efficient data retrieval services. It also supports version control and data backup, ensuring data security and reliability[18].

4. Experimental simulation of smart transportation city system

By establishing a virtual model of the smart transportation city system and using virtual simulation technology to simulate the operation and performance of the smart transportation city system, researchers can conduct simulation experiments on computers to test and verify the effects of various traffic control strategies, traffic signals, vehicle driving behavior, etc. For simulation traffic control strategy optimization, traffic signal optimization, vehicle driving behavior simulation, traffic planning evaluation, etc., the following is an experimental simulation explanation using intersection traffic light control simulation as an example.

4.1. Building and Debugging Traffic Light Scenes at Intersections

According to the overall design scheme of the intersection traffic light system, model intersections, traffic lights and other equipment models are used, and a virtual scene is built using the Unity physics engine platform. The scene of intersection traffic lights is simulated through 3D indicator light commands, giving the objects in the scene actual scene effects. In the process of scene construction[6], it is necessary to achieve a reasonable layout and correct loading of instructions, so that the logic, hierarchy, and steps of the scene are clear and clear.

Firstly, based on the actual scene of traffic lights at intersections and the relevant knowledge of Unity, a task implementation plan is formulated. Then, the task of collecting data related to building and debugging Unity scenes is completed, corresponding equipment and resources are prepared, and scene variables and scripts are set.

Finally, the scene was created, set up, and variables were loaded using Unity software, and debugging was completed using PLC industrial simulation software.

4.2. Develop a PLC Program for the Intersection Traffic Light System

Write a running program using Mitsubishi programming software GXWorks3, write the variables in the scene into the general software component comments of the program, and use these variables to complete the PLC based intersection traffic light control system program. During the programming process, it is necessary to ensure that there are no errors in the conversion and that the logical relationships of the program are clear and concise.

Firstly, complete the collection of data related to the programming of PLC programs, prepare the corresponding equipment and resources, and draw the timing diagram of the intersection traffic light system and the traffic light simulation control wiring diagram, as shown in Figure 2. And set up the scene by drawing a traffic light simulation control wiring diagram.

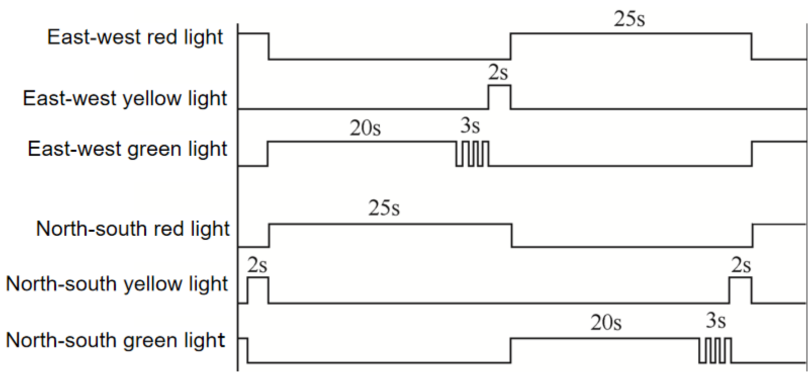

Figure 2. Timing diagram of traffic light system at intersections

After setting up the scene, you can start writing PLC software programs. By creating new scenes and commenting on software components, you can write PLC programs. First, set a timer, which is the total duration of one cycle at the north-south intersection. The "Value Out" port of the timer can output the real-time value of the timer. The real-time value can be divided into numerical regions through numerical comparison instructions, and the results of each region can be output to easily implement the traffic light control system. The TIMER_100-FB-M timer does not have an automatic loop function[6]. Through the "Status" port of the timer, when the timing is completed, it can output variables, and then use this variable and the rising edge to output PLS instructions to refresh the timer. The north and south timers are set as shown in Figure 3.

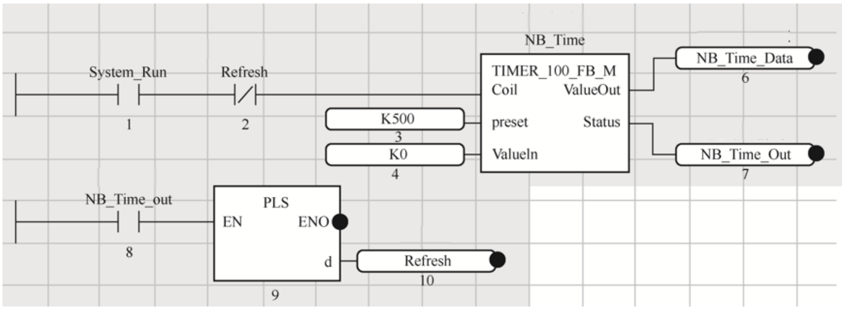

Figure 3. North South Timer Settings

The first step in writing a PLC program for the intersection traffic light system is to define variables that represent the status of traffic signals and time counters. TrafficLightState: represents the current state of the traffic light (e.g. red, green, yellow); GreenTime: The time (in seconds) when the green light is on; RedTime: The time (in seconds) when the red light is on; YellowTime: The time (in seconds) when the yellow light is on; VehicleDetected: Indicates whether a vehicle has been detected (Boolean, True or False).

In the main program, we update the status of traffic lights based on their current status and vehicle detection status. The main program is as follows:

Algorithm 3: Program TrafficLight Controller

```
PROGRAM TrafficLightController
VAR_INPUT
  greenTime : TON;          // Green light time setting
  redTime : TON;            // Red light time setting
  yellowTime : TON;         // Yellow light time setting
  vehicleDetected : BOOL;   // Vehicle detection signal
END_VAR
VAR_OUTPUT
  // The current status of traffic lights (red, green, yellow)
    trafficLightState : BOOL;
END_VAR
VAR_TIME
    elapsedTime : TONR;        // Elapsed Time
END_VAR
BEGIN
    IF vehicleDetected THEN  // If a vehicle is detected
// Set to red or green light, depending on the previous state
        trafficLightState := TRUE;
        // If the current light is red or green and no vehicle is detected, switch to yellow light
        IF trafficLightState AND NOT vehicleDetected THEN
            trafficLightState := FALSE;  // Set to yellow light
        END_IF
    ELSE  // If no vehicle is detected
        trafficLightState := NOT trafficLightState;  // Switch to a light of another color
    END_IF
    // If the time passed exceeds the green light time and the current light is green, switch to the red
  light
    IF elapsedTime >= greenTime AND trafficLightState THEN
        trafficLightState := FALSE;  // Set to red light
    // If the time passed exceeds the red light time and the current light is red, switch to the green
  light
    ELSIF elapsedTime >= redTime AND trafficLightState THEN
        trafficLightState := TRUE;  // Set to green light
    END_IF
END_PROGRAM
```

4.3. Simulation Communication of Traffic Light Scenes at Crossroads

Based on the previous scenario settings and PLC programming, the communication between PLC3D industrial simulation software and PLC programs requires the installation of a protocol, and then the insertion of an encryption dog USB drive to start the PLC3D service. After starting the PLC3D industrial simulation software, click the "Simulation Start" button in the PLC program, PWR and P RUN lights up green, simulation successful.

5. Conclusion

In summary, the smart transportation city system based on digital twin can effectively improve the operational efficiency and safety of urban transportation, and is an effective way to solve urban congestion problems. By using advanced technical means and intelligent decision-making support, it can achieve functions such as path planning, traffic flow management, accident warning, and public transportation optimization, thereby improving the management efficiency of urban transportation, increasing road traffic efficiency, optimizing public transportation services, and improving citizens' travel experience, effectively promoting the sustainable development of smart cities. In the future, the development of smart transportation cities will pay more attention to personalized services and cross-sector cooperation, injecting new impetus into the sustainable development of cities.

References

[1] Lv Zhihan. Digital Twin. Beijing: Tsinghua University Press, 2023:15-179.
[2] Chen Chen, Chen Changjin. Discussion on Traffic Congestion Governance in Smart Cities Based on Intelligent Transportation Systems. Heilongjiang Transportation Science and Technology, 2023 (1): 154-156.
[3] Saleemi Hina, Rehman Zia Ur, Khan Ammad Hassan, Aziz Amer. Effectiveness of Intelligent Transportation System: case study of Lahore safe city. Transportation Letters, 2022 (14): 898-908.
[4] SerranoHernandez Adrian, Ballano Aitor, Faulin Javier. Selecting Freight Transportation Modes in Last-Mile Urban Distribution in Pamplona (Spain): An Option for Drone Delivery in Smart Cities. Energies, 2021 (14):178-193.
[5] Saric Andrej, Zakarija Ivona, Batos Vedran, Krile Srecko. Smart City Decision Making System Based on Event-driven Platform. LOGI – Scientific Journal on Transport and Logistics, 2021 (12) :99-110.
[6] Wu Xiaobing, Zhou Tong, Li Shizhao. Production and debugging of industrial digital twins. Beijing: People's Posts and Telecommunications Publishing House, 2023:181-197.
[7] Huang Jie, Ji Zhaohua, Liu Yingchao. Digital Twin Technology and Applications.Beijing: Beijing Institute of Technology Press, 2023:85-127.
[8] Chen Yanguang. Digital Twin Application Practice in Data Centers. Beijing: Tsinghua University Press, 2023:16-180.
[9] Rani Preeti, Sharma Rohit. Intelligent transportation system for internet of vehicles based vehicular networks for smart cities. Computers and Electrical Engineering, 2022 (105):69-82.
[10] Wu Tanwei. Application of Artificial Intelligence Technology in Urban Intelligent Transportation Systems. Auto Age. 2021 (05): 179-180.
[11] Huahui Xie, Lili Tu, Jie Fang, Said M, Easa. Proactive Highway Traffic Control with Intelligent Multi-Objective Optimization Algorithm. Proceedings of the Institution of Civil Engineers - Transport. 2019 (11): 1-25.
[12] Shao Zhengxi, Chen Jifeng. Analysis and Application of Urban Intelligent Transportation System Design. Smart Cities. 2023,9(11) :26-29.

[13] Yi Huajun, Wang Kunpeng, Zhang Shumin. Analysis and Application of Urban Intelligent Transportation System Design. Auto Age. 2022 (23) :193-195.
[14] Zhang Xiaojuan. Research on the Elements, Structure and Model of Smart City System. Economy and Management Science, 2020 (4): 107-127.
[15] Gohar Ali, Nencioni Gianfranco. The Role of 5G Technologies in a Smart City: The Case for Intelligent Transportation System. Sustainability, 2021 (13):136-151.
[16] Fan Xingxing, Yao Yuan. Research on the Scheme Design and Construction Effectiveness of Smart Transportation System under the Background of Digital City. Engineering and Technology Research. 2022,7(20): 32-34.
[17] Xingyu Tao,Lan Cheng,Ruihan Zhang,W. K. Chan,Huang Chao. Towards Green Innovation in Smart Cities: Leveraging Traffic Flow Prediction with Machine Learning Algorithms for Sustainable Transportation Systems. Sustainability, 2023(16) :56-69.
[18] Javier Garau Guzman,Victor Monzon Baeza. Enhancing Urban Mobility through Traffic Management with UAVs and VLC Technologies. Drones, 2023(8) :136-151.