A Study of the Application and Impact of Artificial Intelligence in Intelligent Transport Systems

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Abstract: This paper provides an in-depth analysis of the panorama of AI applications in intelligent transportation, explores cutting-edge research on traffic optimization and prediction, and provides a blueprint for future development. The introductory section outlines how AI technology has penetrated all corners of traffic management and its central role in improving traffic efficiency, ensuring traffic safety, and supporting urban planning. In the section on AI applications, we elaborate on the architecture of ITS, technology convergence, and the development of key technologies such as traffic flow analysis and management, autonomous driving technology, and intelligent control of traffic signals. In the section on traffic optimization strategies, we discuss in-depth strategies such as route planning and navigation systems, traffic congestion prediction and mitigation, public transport system optimization, and logistics and distribution route optimization, aiming to enhance the effectiveness of the transport system, reduce traffic congestion, enhance the attractiveness of public transport, and optimize the logistics and distribution processes through advanced technological means. In the discussion of traffic prediction models and algorithms, we carefully compare and analyze the application of time series analysis, machine learning algorithms, deep learning techniques, and integrated learning methods in traffic prediction. Through case studies of domestic and international intelligent transport projects, this paper demonstrates the results of AI technology in practical applications and reveals the limitations and challenges in current research. In the conclusion section, we review AI's remarkable achievements in intelligent transport and provide forward-looking insights into future research directions, emphasizing the critical importance of interdisciplinary collaboration and continuous technological innovation in promoting the development of intelligent transport. In summary, this paper provides readers with a comprehensive and in-depth perspective to understand and advance the application of AI in the field of intelligent transport.

Keywords: AI technology; intelligent traffic; traffic flow prediction; traffic optimization

1. Introduction

In the wave of rapid urbanization in the 21st century, problems such as traffic congestion, frequent accidents, and environmental pollution have become common challenges for major cities around the world. Traditional traffic management methods are inadequate in dealing with these complex problems. Fortunately, the rapid development of Artificial Intelligence (AI) technology provides an unprecedented opportunity to revolutionize intelligent transport systems by simulating human cognitive processes, and processing and analyzing large amounts of complex traffic data to optimize and predict traffic flows.

An intelligent transport system is not just a collection of technologies, it represents a new concept of traffic management, i.e. the optimal allocation of traffic resources through real-time data analysis and intelligent decision support. In this context, traffic optimization and prediction have become a hot research topic. Traffic optimization focuses on how to achieve the best traffic flow state under limited resources through scientific planning and management. Traffic forecasting, on the other hand, focuses on using historical and real-time data to predict future traffic conditions so that measures can be taken in advance to avoid or reduce traffic congestion.

This review aims to provide insights into the application of AI technologies in the field of intelligent transportation, especially the research progress in traffic optimization and prediction. We will review the relevant literature and analyze how AI technologies play a role in different transport scenarios and how they can help us understand and improve complex transport systems. Through this review, we expect to provide insights into the future direction of intelligent transport and provide valuable references for policymakers, researchers, and engineers.

2. Application of Artificial Intelligence in Intelligent Transportation

2.1 Overview of Intelligent Transport Systems

Intelligent Transport System (ITS) is a comprehensive traffic management system that integrates a variety of modern technologies such as information technology, data communication technology, sensor technology, electronic control technology, computer processing technology, etc. The goal of ITS is to achieve intelligent management of the traffic system through real-time data collection, processing, and exchange, to improve traffic efficiency, reduce traffic congestion, reduce the rate of accidents, and reduce environmental pollution. AI technology plays a central role in ITS by analyzing and learning from a large amount of traffic data to provide decision support and automated control, thus making the traffic system more intelligent and efficient [1].

2.2 Traffic Flow Analysis and Management

Traffic flow analysis is the basis for understanding traffic behaviour and optimizing traffic management. The application of AI technology in this field is mainly reflected in the deep mining of traffic data and pattern recognition. Through machine learning algorithms, AI is able to analyze historical traffic data, predict trends in traffic flow, identify patterns of traffic congestion, and make optimization recommendations accordingly. For example, Baidu Maps uses AI to analyze users' mobile data, update traffic conditions in real time, and provide users with the best routes to avoid congestion [2]. In addition, AI can test different traffic management strategies by simulating traffic flow to find the optimal solution.

2.3 Development and Challenges of Autonomous Driving Technology

Automatic driving technology is one of the most revolutionary applications of AI in the field of transport. By integrating advanced sensors, high-precision maps, and powerful computing platforms, self-driving vehicles can sense their surroundings, react quickly, and navigate autonomously. Although significant progress has been made in the laboratory and in closed environments, large-scale deployment of autonomous driving technology on public roads still faces many challenges, including issues such as technological maturity, laws and regulations, ethics and social acceptance, etc. The application of AI in autonomous driving technology not only needs to solve complex perception and decision-making problems but also needs to consider human-computer interaction and user experience [3].

2.4 Intelligent Control of Traffic Signals

Intelligent control of traffic signals is an intuitive embodiment of the application of AI technology in intelligent transport. Traditional traffic signals usually use a fixed schedule, which cannot be flexibly adjusted according to real-time traffic conditions technology can dynamically adjust the switching time of signals by analyzing real-time traffic flow data, to reduce the waiting time of vehicles and improve the efficiency of intersections. For example, an Adaptive Traffic Control System (ATCS) is a kind of intelligent signal control system using AI technology, which can automatically optimize the signal timing scheme according to the real-time changes of traffic flow [4].

3. Traffic Optimization Strategies

3.1 Route Planning and Navigation System

3.1.1 Technical basis of real-time route planning

The core task of real-time route planning is to provide users with the fastest path selection in the rapidly changing traffic environment. This process is built on a solid technical foundation, mainly including the following aspects:

(1) Dynamic routing algorithms

Traditional routing algorithms, such as Dijkstra's algorithm and A* search algorithm, although excellent in static networks, appear to be inadequate in the face of real-time traffic changes. For this reason, dynamic routing algorithms such as DTA (Dynamic Traffic Assignment) came into being, which not only consider the static properties of the traffic network but also incorporate real-time traffic flow data, making the calculated paths more in line with the actual traffic conditions [5].

(2) Real-time traffic data collection

The collection of real-time traffic data is a prerequisite for the realization of dynamic routing. Modern technologies such as GPS tracking, traffic cameras, road sensors, etc., can capture real-time vehicle speed, traffic flow, road status, and other information. These data are like flowing blood, providing a constant stream of vitality for real-time route planning.

(3) Cloud computing and big data analysis

With the surge in data volume, a single device can no longer carry such a huge computing task. The emergence of cloud computing platforms, with their powerful distributed computing capability, has become the key to handling massive traffic data. Combined with big data analysis technology, the cloud platform can quickly filter and integrate data to provide users with accurate route suggestions.

3.1.2 The way navigation systems help users avoid congestion

The navigation system plays an important role in helping users avoid traffic congestion, and its functions are mainly reflected in the following aspects:

(1) Real-time traffic information integration

The navigation system, like a smart guide, monitors and integrates real-time traffic information from all directions. It not only pays attention to the location of congested areas, but also closely tracks accident reports, road construction, and other dynamic information to ensure that users have access to the latest and most accurate traffic conditions.

(2) Dynamic route adjustment

When the navigation system detects that the user is about to encounter congestion, it will quickly activate the emergency mechanism to re-evaluate and recommend a smoother alternative route. This dynamic adjustment ability, like a sharp helmsman, can guide the user to calm waters in the rough sea of traffic [6].

(3) User participation and feedback

Navigation systems also encourage active user participation. Through crowdsourcing, users can report real-time traffic events, such as car accidents and blockages. This first-hand information from users is quickly absorbed by the system and incorporated into route planning, greatly enhancing the timeliness and accuracy of the information. Users are not only the receivers of information, but also the contributors, together weaving a real-time traffic intelligence network covering the whole city.

In summary, real-time route planning and navigation systems effectively help drivers find the best path in the complex traffic network, avoid congestion, and improve travelling efficiency through advanced technical means and user interaction. With the continuous progress of technology and the gradual cultivation of user habits, this system will continue to evolve and bring more possibilities for urban traffic management.

3.2 Traffic Congestion Prediction and Mitigation

3.2.1 Construction of traffic congestion prediction model

To construct an accurate traffic congestion prediction model, researchers need to go through a series of well-designed steps to ensure the accuracy and practicality of the model.

(1) Data preprocessing

Data preprocessing is an indispensable part of the initial stage of model construction. Raw traffic data often contain noise and outliers, which need to be removed by cleaning to eliminate these disturbing factors. In addition, data standardization is also necessary, which helps to eliminate the effects of different units of measurement, making the data more suitable for model training and analysis.

(2) Feature engineering

Feature engineering is the key to the success of the model. In this stage, researchers need to carefully select features that are closely related to traffic congestion. These features may include time, date, weather conditions, special events, and so on. Through in-depth analysis of these features, the model can better understand the dynamics of traffic flow and thus make more accurate predictions.

(3) Model selection and training

Choosing the right prediction model is crucial to the final effect of the model. Time series analysis, regression models, neural networks, etc. are commonly used prediction models. Researchers need to select the most appropriate model according to the characteristics of the specific problem and the characteristics of the data. After the model is selected, it is trained using historical data so that the model can learn and master the patterns and laws of traffic congestion.

(4) Model validation and optimization

Model validation and optimization is an iterative process. Through methods such as cross-validation, researchers can assess the predictive performance of the model. If the model does not perform as expected, it needs to be adjusted and optimized based on the feedback results to improve the accuracy and robustness of the model. This process may require several iterations until the model reaches a satisfactory level of prediction.

3.2.2 Exploring the effectiveness and implementation difficulties of mitigation strategies

There are various mitigation strategies for traffic congestion, but their effectiveness and implementation difficulties are also worth exploring in depth.

(1) Effectiveness:

Intelligent signal control systems can effectively balance the traffic flow in all directions and reduce waiting time and congestion by dynamically adjusting the signal cycle. However, the implementation of such a system requires a high degree of technical support and accurate data analysis to ensure that the signals are adjusted to the changing traffic conditions [7].

The installation of variable message signs at critical road sections can divert traffic pressure by guiding drivers to less congested paths in real-time. However, the success of this strategy relies on accurate information updates and the degree to which drivers trust and adopt the information.

Traffic pressure can be effectively dispersed by implementing measures such as restricting traffic during peak hours and encouraging staggered trips. However, these measures may cause inconvenience to the travelling public, so adequate communication and reasonable compensation measures are needed to gain public support before implementation.

(2) Implementation difficulties:

The effectiveness of any mitigation strategy is based on data. Inaccurate or outdated data can lead to ineffective strategies or even exacerbate congestion. Therefore, ensuring the accuracy and timeliness of the data is the first task in implementing the strategy [8].

Existing technologies and road infrastructures may not be able to fully meet the implementation requirements of some strategies. For example, the rollout of ITS requires extensive hardware upgrades and software development, which is a huge challenge for many cities.

The lack of appropriate policy support and regulatory framework can also be a barrier to the implementation of strategies. The government needs to formulate clear policies and regulations to provide legal protection and financial support for traffic congestion mitigation measures.

3.3 Optimization of the Public Transport System

3.3.1 Optimization methods for public transport systems

The optimization of public transport systems is a systematic project involving many levels of scheduling, management and service. The following are some key optimization methods:

(1) Intelligent dispatching system

In the age of intelligence, the scheduling of public transport no longer relies solely on empirical judgment but shifts to an intelligent scheduling system based on big data and advanced algorithms. Such systems can monitor the operating status of vehicles, traffic flow, and passenger demand in real-time, and dynamically adjust departure intervals and routes to maximize operational efficiency. Through intelligent scheduling, it can not only reduce idling and congestion but also effectively shorten the waiting time of passengers and improve the overall transport efficiency.

(2) Passenger information services

The modernization of passenger information services is essential to enhance the attractiveness of public transport. With the help of mobile applications, electronic stop signs, and other high-tech means, passengers can easily access real-time arrival information, vehicle congestion, transfer guides, and other practical information. The provision of these services not only facilitates trip planning but also enhances the transparency and predictability of public transport, thereby improving the overall passenger experience.

(3) Ticketing system modernization

Modernizing the ticketing system is an important part of enhancing the convenience of public transport. By promoting e-ticketing and mobile payment, passengers can avoid the hassle of queuing to purchase tickets and can complete the ticketing operation with just the touch of a finger. This contactless ticketing experience not only saves time, but also reduces health hazards arising from cash transactions, especially in today's world of normalized epidemic prevention and control.

(4) Multi-modal intermodal transport

Multi-modal intermodal transport refers to the integration of different modes of transport, such as buses, subways and shared bikes, to provide passengers with a one-stop travel solution. The advantage of this mode is that it can make full use of the advantages of various modes of transport to form complementary, thus providing passengers with more flexible and efficient travel options. For example, through an integrated transport application, passengers can plan a full route from their doorstep to their destination, whether by walking, cycling or taking the bus or MTR, seamlessly.

3.3.2 Enhancing the attractiveness and service quality of public transport

To further enhance the attractiveness and service quality of public transport, the following measures can be taken:

Firstly punctuality is one of the key indicators of public transport service quality. Ensuring the reliability and punctuality of public transport through optimizing scheduling, improving infrastructure and strengthening management can enhance passengers' confidence in public transport, thus attracting more people to choose public transport for travel. Secondly, appropriately increasing the frequency of public transport services during peak hours and on popular routes can effectively ease congestion and reduce passengers' waiting time. Such flexible adjustments in response to high demand can significantly enhance passenger satisfaction and loyalty. Reinvesting in new and comfortable modes of transport with modern facilities such as spacious seats, air-conditioning systems, and Wi-Fi can significantly enhance passengers' travelling experience. Meanwhile, improving boarding and alighting facilities at stations, such as installing lifts, escalators, and barrier-free access, can also make all passengers, especially the elderly and those with mobility problems, feel the warmth and convenience of public transport. Finally, to meet the needs of specific groups, provide customized public transport services, such as special lines for students, night buses, tourist sightseeing routes, etc., which can not only meet the special needs of different passengers but also increase the market competitiveness of public transport.

3.4 Optimization of Logistics and Distribution Path

3.4.1 Key technologies and algorithms for logistics path planning

In the logistics industry, efficient path planning is the key to ensure the quality of distribution services and cost control. The following are several key techniques and algorithms that play an important role in logistics path planning:

(1) Vehicle path problem (VRP) algorithms

The Vehicle Path Problem (VRP) is a classic problem in logistics, which involves how to assign appropriate distribution tasks to a group of vehicles and find the optimal or near-optimal paths while satisfying a series of constraints (e.g., vehicle capacity, service time window, vehicle type, etc.) The goal of the VRP algorithm is usually to minimize the total distance travelled, time, or cost, which is important for reducing the operation cost of the logistics company cost is of great significance.

(2) Heuristic algorithm

In the face of large-scale, complex logistics path planning problems, traditional mathematical planning methods may make it difficult to find a satisfactory solution within an acceptable time. Therefore, heuristic algorithms such as genetic algorithms, ant colony algorithms, simulated annealing, etc., are widely used because of their ability to explore the solution space and find a near-optimal solution in a short time. These algorithms can find effective path solutions under complex constraints by simulating the principles of nature or physical processes.

(3) Multi-objective optimization

In real-world logistics and distribution, decision-makers often need to consider multiple conflicting objectives at the same time, such as cost, time, service quality, environmental impact, and so on. Multi-objective optimization algorithms can help logistics companies find a balance point between these objectives, thus maximizing the overall benefits. This approach emphasizes reaching a consensus among different stakeholders rather than simply pursuing the optimality of a single objective.

3.4.2 Economic and environmental benefits of logistics and distribution optimization

Optimizing logistics and distribution paths not only brings significant economic benefits but also has a positive environmental impact:

Through accurate path planning, logistics companies can significantly reduce unnecessary travelling distance and time, thus reducing fuel consumption, vehicle maintenance costs, and labour costs. Such cost savings are directly reflected in a company's financial statements, increasing its profit margin. Optimized distribution routes enable faster delivery of goods and shorter delivery times from the warehouse to the customer. This not only improves customer satisfaction, but also helps the enterprise respond faster to market changes and enhances its market competitiveness. Optimization of logistics and distribution reduces vehicle mileage and idling, which means less carbon emissions and air pollution. In addition, fewer vehicles on the road help reduce traffic congestion and improve the overall efficiency of urban transport. These environmental benefits are in line with the concept of sustainable development and help companies build an environmentally friendly image, while also bringing long-term benefits to society.

In summary, logistics and distribution route optimization can not only improve the operational efficiency and economic benefits of enterprises, but also promote environmental protection and sustainable development. With the progress of technology and the continuous optimization of algorithms, the optimization of logistics and distribution will play a greater role in the future and become an important driving force to promote the high-quality development of the logistics industry.

4. Traffic Prediction Models and Algorithms

4.1 Application of Time Series Analysis in Traffic Flow Prediction

As a powerful statistical tool, time series analysis has been increasingly widely used in the field of traffic flow forecasting, which provides traffic managers with a powerful means to predict future traffic conditions by mining the intrinsic laws in historical data. The core of time series analysis lies in identifying and utilizing the patterns of data changes over time.

(1) Smoothness assumption

Smoothness is a key concept in time series analysis, which assumes that the statistical characteristics (e.g., mean, variance) of time series data are constant at different points in time. In other words, the distribution of the data does not change significantly over time. In practice, non-stationary time series usually need to be transformed into stationary series through processing such as differencing to facilitate analysis and modelling.

(2) Autocorrelation

Autocorrelation refers to the correlation that exists between data points at different points in time in a time series. This correlation can be positive (data at one point in time has a positive relationship with data at a previous point in time) or negative (inverse relationship). Autocorrelation is the basis for time series modelling, which reflects the continuity and trend of data over time.

(3) Seasonality and trend

Seasonality refers to the periodic repeating pattern that exists in the time series data, such as the daily, weekly, or yearly fixed pattern of change. Trend refers to the long-term upward or downward trend of data over time. In traffic flow data, seasonality and trends are usually manifested in cyclical phenomena such as morning and evening peaks, weekend troughs, and holiday peaks, as well as trends in urban development and population growth.

4.2 Comparison of Machine Learning Algorithms in Traffic Prediction

Machine learning, as an important branch of artificial intelligence, has shown great potential for its application in the field of traffic prediction. Different types of machine learning algorithms have their own merits, below we will compare and analyze the performance of several common algorithms in traffic prediction and their advantages and disadvantages.

4.2.1 Decision trees and random forests

Decision trees are intuitive and easy-to-understand algorithms that make predictions by creating a structure similar to a flowchart. Decision trees are good at dealing with non-linear relationships and can capture complex patterns in traffic flow data well. However, decision trees are sensitive to noise, which can lead to overfitting, and their performance can be limited especially when dealing with large-scale datasets.

Random forest, on the other hand, improves the stability and accuracy of prediction by integrating multiple decision trees. It reduces the risk of overfitting through random sampling and feature selection, but accordingly, the model is less interpretable because the final prediction is the result of voting by multiple decision trees.

4.2.2 Support vector machines (SVM)

SVM is a powerful tool for classification and regression, especially for small datasets. It performs well in high-dimensional spaces and is capable of handling non-linear problems. However, SVM is computationally expensive when dealing with large-scale and high-dimensional data, and the performance of the model relies heavily on the choice of parameters, with a complex parameter tuning process.

4.2.3 Neural networks

Neural networks, especially Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), perform well when dealing with spatio-temporal data. CNNs are good at capturing local features in image data [9], while RNNs and their variants, LSTMs (Long and Short-Term Memory Networks) and GRUs (Gated Recurrent Units), can effectively deal with temporal dependencies in sequence data. Neural networks are capable of capturing very complex patterns, but they are expensive to train, require large amounts of labelled data, and present challenges in model debugging and interpretation.

4.3 Advances in Deep Learning for Traffic Pattern Recognition

Deep learning technology, with its powerful feature learning and pattern recognition capabilities, has made significant progress in the application of traffic. In particular, deep learning models have shown great potential in traffic pattern recognition and prediction.

4.3.1 Application of CNN in traffic pattern recognition

A convolutional neural network (CNN) is a deep learning model particularly suitable for processing image data. In the field of traffic surveillance, CNNs are used to analyze video streams from traffic cameras to automatically identify and extract traffic patterns from them. For example, CNNs can detect key information such as traffic flow density, vehicle type, and vehicle speed, and even identify traffic violations such as running red lights and driving against traffic. In this way, CNN not only improves the automation level of traffic monitoring, but also provides rich data support for traffic management and decision-making.

4.3.2 Application of RNN and LSTM in traffic flow prediction

Recurrent Neural Networks (RNN) and their variants, such as Long Short-Term Memory Networks (LSTMs), are specifically designed to process sequential data and can capture temporal dependencies in the data [10]. In traffic flow prediction, RNN and LSTM models can analyze historical traffic flow data and predict future traffic conditions. These models can take into account temporal variations in traffic flow, such as the difference between weekdays and weekends, and the characteristics of the morning and evening peaks, to provide more accurate prediction results.

4.4 Advantages of Integrated Learning Methods in Multi-source Data Fusion Prediction

In the complex and changing field of traffic prediction, it is often difficult for a single prediction model to comprehensively capture all the influencing factors and changing patterns. The emergence of integrated learning methods provides an effective way to solve this challenge. Integrated learning not only improves the accuracy of prediction but also enhances the robustness and flexibility of the model by bringing together the wisdom of multiple base learners.

4.4.1 Basic idea of integrated learning methods

The core idea of integrated learning lies in the concept of "many hands make light work", i.e., by combining the prediction results of multiple learners, we can achieve better performance than a single learner. The following are some common integrated learning strategies:

(1) Voting

The voting method is a simple and intuitive integration strategy that decides the final prediction by the prediction results of most base learners. In traffic prediction, if multiple models are pointing to the same prediction direction, the credibility of this prediction result is much higher.

(2) Stacking

Stacking uses a meta-learner to combine the outputs of multiple base learners and learns how to optimally combine the predictions of these base learners to improve the overall prediction performance. In multi-source data fusion prediction, the Stacking method can effectively exploit the complementarities between different data sources and models.

(3) Bagging and boosting

Bagging (self-help aggregation method) and Boosting (boosting method) are two commonly used integrated learning frameworks. Bagging constructs multiple independent base learners by random sampling and then combines their predictions by voting or averaging, which is mainly used to reduce the variance of the model. Boosting, on the other hand, reduces model bias by iteratively adjusting sample weights so that subsequent base learners pay more attention to samples that were misclassified by previous learners.

4.4.2 Effectiveness of integrated learning in fusing multi-source data for traffic prediction

The application of integrated learning in traffic prediction, especially in the case of fusing multi-source data, shows significant advantages:

By combining predictions from different models, integrated learning can reduce the errors of individual models and improve the accuracy of the overall prediction. In traffic prediction, this means being able to more accurately predict key metrics such as traffic flow and congestion. Integrated models are typically more resistant to noise and outliers than single models. In complex traffic environments, a variety of uncertainties can cause a single model's predictions to be biased, and integrated learning is better able to address these challenges through the collective intelligence of multiple models. Integrated learning can flexibly combine different types of data sources and models to adapt to complex and changing traffic conditions. For example, information from multiple data sources such as traffic cameras, sensors, social media, etc., as well as model predictions based on different methods such as time series analysis, machine learning, deep learning, etc., can be effectively fused by integrated learning methods.

The application of integrated learning methods in multi-source data fusion prediction provides an efficient and robust solution for traffic prediction. By reasonably selecting and combining different prediction models and data sources, integrated learning not only improves the accuracy and robustness of prediction, but also adapts to complex and changing traffic environments, providing strong support for the construction and operation of intelligent transport systems. In the future, with the increase in data volume and the improvement of computing power, the application of integrated learning in the field of traffic prediction will be more extensive and deeper.

5. Successful Case Analysis of Intelligent Transportation Projects at Home and Abroad

5.1 Domestic Case: Shanghai Intelligent Transport System

In the wave of globalization and modernization, Shanghai, the Pearl of the Orient, attracts the world's attention with its unique charm and vitality. However, with the acceleration of urbanization and population explosion, traffic management has become a difficult problem in front of Shanghai. To meet this challenge, the Shanghai Municipal Commission of Transportation launched an Intelligent Transport System (ITS), which is not only a product of technological innovation but also the epitome of smart city construction. Shanghai's Intelligent Transport System (ITS) is a comprehensive traffic management system that uses cutting-edge technologies such as big data analytics, cloud computing, and the Internet of Things (IoT) to build an efficient and intelligent traffic management platform. The goal of the system is to optimize urban traffic flow, enhance the service efficiency of public transport, reduce traffic congestion and accident rates, and thus improve the travel experience and quality of life of citizens.

Behind Shanghai ITS is a vast data network. The system integrates data from multiple sources such as traffic cameras, in-vehicle GPS, and mobile applications to form a real-time traffic data lake. Through advanced big data analytics, the system can monitor traffic conditions in real-time and predict future traffic flows and potential congestion points. For example, the system can predict the traffic flow of a road section during a specific period based on historical data and current factors such as weather and events, so that scheduling and management measures can be made in advance. Another highlight of Shanghai ITS is its adaptive signal control system. This system is capable of automatically adjusting the signal timing scheme of an intersection based on real-time traffic flow data collected to maximize the efficiency of the intersection [11]. During peak hours, the system can extend the green time in the busy direction, while during off-peak hours it can shorten the waiting time, ensuring smooth traffic flow without wasting resources. ITS Shanghai also places special emphasis on public participation and feedback. Through a dedicated mobile application, citizens can not only receive real-time traffic information but also get personalized route suggestions. In addition, citizens can participate in traffic management practices by reporting traffic accidents, road damage and other issues through the app. This interaction not only improves citizens' participation and satisfaction, but also provides valuable feedback to traffic management departments.

For example, on a main road in Pudong New Area, the average speed of the road was increased by 20 per cent and congestion time was reduced by 30 per cent through the implementation of intelligent signal control. Meanwhile, through the promotion of mobile applications, more than a million citizens have started to use the real-time traffic information service. They can plan their journeys based on the best-recommended routes, avoiding unnecessary congestion and delays. Shanghai's elevated road monitoring system monitors traffic flow and road conditions on elevated roads in real-time through cameras and sensors installed at key nodes. The system can automatically detect traffic accidents and congestion and disseminate real-time information through traffic guidance screens to guide drivers in choosing the best driving routes. At the same time, the system can also link up with the traffic signal control system to adjust the signal timing of the surrounding intersections to ease traffic pressure. Shanghai's traffic offence monitoring systems use high-definition cameras and image recognition technology to automatically monitor and record traffic offences, such as running red lights, speeding, and driving outside of prescribed lanes. These systems not only improve the efficiency and fairness of traffic enforcement but also effectively deter traffic offences and improve road traffic order. Shanghai's Emergency Rescue Response System achieves rapid response to traffic accidents and emergencies by linking up with traffic police, firefighting and medical departments. When a traffic accident occurs, the system can automatically send alarm information to the relevant departments and optimize the route of rescue vehicles according to the location and severity of the accident, ensuring that rescuers can arrive at the scene quickly.

The Shanghai ITS is not only a model of technological innovation, but also a vivid practice of smart city construction. By integrating and analyzing big data, implementing intelligent signal control, and encouraging public participation, Shanghai is gradually building a more efficient, convenient and safer traffic environment. As technology continues to advance and applications deepen, we have reason to believe that Shanghai's ITS will provide valuable experience and inspiration to other cities around the world.

5.2 Overseas Case: Singapore Electronic Road Pricing (ERP) System

Singapore Electronic Road Pricing (ERP) is an innovative initiative taken by the Singaporean government to ease urban traffic congestion. The system adjusts toll rates according to real-time traffic conditions through a dynamic pricing mechanism, effectively diverting traffic during peak hours and improving the efficiency of urban roads.

The core of ERP is its dynamic pricing mechanism. The system automatically adjusts toll rates for different periods and different road sections based on real-time traffic flow data. For example, during peak hours and busy road sections, the system will automatically raise the toll rates to incentivize drivers to choose off-peak travelling hours, or to choose public transport. This dynamic pricing mechanism reflects changes in traffic conditions promptly, providing drivers with more flexible and economical travelling options. Another feature of the ERP system is its seamless payment experience. When the vehicle passes through the ERP toll gate, the system will automatically identify the vehicle, and deducts the corresponding expense through the vehicle electronic label (ETC) or the prepaid card. This contactless payment method greatly reduces the time drivers spend stopping to pay their tolls, improves traffic flow, and also reduces errors and disputes that may occur during manual toll collection. Of course, the Singaporean government's strong investment in public transport and its policy of encouraging green travelling have also laid the foundation for the success of the ERP system. By providing public transport concessions, building more MRT lines and bus stops, and promoting electric vehicles, the government encourages the public to choose public transport, thus reducing the use of private cars. In addition, the government has maintained the order and effectiveness of the ERP system's operation by cracking down on illegal road use through legislative means.

After the implementation of the ERP system, the Singaporean government found that the traffic flow on the city's main roads during peak hours dropped significantly. For example, by adjusting toll rates through the ERP system, the number of vehicles entering the main roads in the city center during peak hours was reduced by about 20%, thus effectively easing traffic congestion. At the same time, through data analysis, the Government found that more citizens chose to travel during off-peak hours, which not only reduced the pressure of traffic flow during peak hours but also provided a more comfortable travelling environment for the public. The implementation of the ERP system has also improved traffic smoothness. By means of automatic toll deduction, the time for vehicles to pass through the ERP gates has been reduced from tens of seconds to a few seconds, which greatly reduces the waiting time in the queue. In addition, as vehicles do not need to stop to pay tolls, drivers' attention can be focused on driving, thus improving driving safety. In addition to improving traffic conditions, ERP systems also bring economic benefits. By reducing congestion and accidents, the ERP system saves the government a lot of money in traffic management costs. At the same time, due to the increase in vehicle travelling speed, fuel consumption is reduced accordingly, which reduces energy consumption and environmental pollution to a certain extent.

To sum up, the implementation of the Electronic Road Pricing (ERP) system in Singapore has achieved remarkable results, providing an effective solution to alleviate urban traffic congestion and improve traffic efficiency and safety.

6 Summary

6.1 Main Contributions of Artificial Intelligence in the Field of Intelligent Transportation

Artificial Intelligence (AI) technology has become an important driving force for innovation in the field of intelligent transport, and its application not only enhances the efficiency and safety of the transport system but also greatly improves the user's travelling experience. The following is an in-depth description of the main contributions of AI in the field of intelligent transport:

(1) Traffic flow optimization

By integrating and analyzing a large amount of traffic data from various sensors, AI algorithms can monitor traffic conditions in real-time and make predictions about future traffic flows. This predictive capability enables intelligent signal control systems to optimize traffic flow by dynamically adjusting signal cycles according to actual demand. For example, the green time is increased during peak hours to reduce vehicle waiting time, while the green time is reduced during off-peak hours to avoid wasting resources. This refined management significantly reduces traffic congestion and delays and improves road usage efficiency.

(2) Intelligent navigation system

Intelligent navigation systems based on machine learning and big data analysis can provide users with personalized route suggestions by taking into account a variety of factors such as historical traffic data, real-time road condition information and weather forecasts. These systems not only help drivers avoid congested roads but also provide a variety of route options based on user preferences and needs (e.g., shortest time, least tolls, etc.). In addition, intelligent navigation systems can update road condition information in real-time to help drivers make instant adjustments during the driving process, thus improving overall driving efficiency and safety.

(3) Accident detection and response

By integrating high-resolution cameras and advanced image processing technologies, AI systems can monitor road conditions in real time and respond immediately when a traffic accident is detected. These systems can quickly identify the exact location, type and severity of the accident and automatically notify the nearest rescue authorities. In this way, AI systems greatly shorten accident response time and reduce the time required for rescue personnel to arrive at the scene, thereby reducing secondary injuries and traffic congestion that may result from accidents.

(4) Public transport management

The application of AI technology in the field of public transport, especially in the scheduling and maintenance planning of public transport vehicles, has shown great potential. By analyzing passenger flow data and vehicle operating status, AI systems can optimize bus departure intervals to ensure that vehicles meet passenger demand during peak hours and avoid over-service during off-peak hours. In addition, AI can predict vehicle maintenance needs and schedule repairs in advance, reducing disruptions due to vehicle breakdowns. These improvements not only increase service efficiency but also enhance overall passenger satisfaction.

(5) Self-driving vehicles

The development of self-driving technology marks a major turning point in the transport industry, and the core technology behind it is AI. Self- driving vehicles rely on advanced AI algorithms to process large amounts of data from LIDAR, cameras, and other sensors to achieve an accurate perception of their surroundings. These vehicles can make autonomous decisions such as avoiding obstacles and obeying traffic rules, as well as controlling the acceleration, braking and steering of the vehicle. The development of autonomous driving technology is not only expected to significantly reduce traffic accidents, but also to improve road capacity, reduce energy consumption, and lay the foundation for future intelligent transport systems.

(6) Personalized traffic services

Another important contribution of AI technology is the provision of personalized traffic services. By analyzing the user's travel history and preferences, the AI system can provide the user with customized travel advice, including the best travel times, routes and modes of transport. For example, for users who frequently need to travel to the same location, the AI system can recommend a route that is both efficient and comfortable and provide real-time updates on traffic information. In addition, the AI can automatically plan journeys and even book transport and parking spaces according to the user's schedule and preferences, which greatly facilitates the user's daily travel.

6.2 Research Limitations

6.2.1 Data quality and availability

Data is the foundation of ITS, and its quality and availability directly affect the accuracy of the model and the reliability of the system. Although modern data collection technologies such as sensors, cameras, and mobile devices provide massive amounts of data, the following problems still exist:

(1) Uneven data quality: data may contain noise and inconsistency due to equipment malfunction, environmental interference, or human error, which requires data cleaning and preprocessing to improve data quality.

(2) Insufficient data integrity: certain key information may be missing, such as specific details of traffic accidents, the exact time and location of road construction, etc., and the incompleteness of such information will affect the predictive ability of the model.

(3) Privacy protection restrictions: with the strengthening of privacy protection regulations, such as the GDPR in Europe, the collection and use of certain types of personal data (e.g., vehicle trajectories, personal information, etc.) is severely restricted, which poses a challenge to data availability.

6.2.2 Model complexity and interpretability

With the application of advanced technologies such as deep learning in traffic prediction, the complexity of models has increased dramatically, which brings a series of problems:

(1) Black-box models: Deep learning models are often regarded as "black boxes" whose internal working mechanisms are not easy to understand, which limits the application of models in scenarios that require a high degree of transparency and interpretability, such as traffic management and decision support.

(2) Model generalization ability: complex models may perform well on specific datasets, but when faced with new and unseen data, their generalization ability may be insufficient, leading to instability in prediction results.

6.2.3 Real-time and computational resources

Real-time traffic prediction has very high requirements for computing resources: processing large amounts of traffic data in real-time requires high-performance computing hardware and optimized software algorithms, while the existing computing infrastructure may not be able to meet the real-time requirements of all application scenarios. While ensuring real-time, the system latency and throughput also need to be considered, which is crucial for user experience and system utility.

6.3 Future Development Direction

The future development of ITS is full of infinite possibilities. With the advancement of technology and the evolution of requirements, future research will focus on multimodal data fusion, reinforcement learning and adaptive systems, edge computing and IoT, sustainability and environmentally friendly traffic management, as well as synergy of policies and regulations.

(1) Multimodal data fusion

Future research will focus more on the fusion of heterogeneous data from multiple sources, which is not only the traditional traffic flow and speed data, but also includes social media, mobile communication data, meteorological information, geospatial data, and so on. By fusing these multimodal data, a more comprehensive and three-dimensional view of traffic conditions can be provided, thus improving the accuracy and reliability of traffic forecasts. For example, real-time discussions on social media can provide information about unexpected events, while mobile communication data can reveal people's travel patterns and trends.

(2) Reinforcement learning and adaptive systems

Reinforcement learning, as an algorithm capable of learning optimal behavioral strategies through trial and error, will play an increasingly important role in traffic management systems. This kind of adaptive system can learn and adjust its strategy independently according to real-time traffic feedback, such as dynamically adjusting signal light timing, optimizing route recommendation algorithms and so on. Through continuous learning and adaptation, the system can better cope with the complex traffic environment and changing traffic demand.

(3) Edge computing and IoT

With the popularity of IoT devices and the development of edge computing technology, the real-time processing of traffic data will be greatly improved. Edge computing allows data to be processed close to where it is generated, reducing delays in data transmission and helping to achieve faster responses and more accurate predictions. At the same time, the application of IoT devices will allow for finer granularity in traffic monitoring and control, thus improving the operational efficiency of the entire transport system.

(4) Sustainability and environmentally friendly traffic management

Against the backdrop of increasing attention to climate change and environmental protection, traffic prediction models will take more account of environmental impacts, such as carbon emissions and energy consumption. This will drive traffic management in a more sustainable and environmentally friendly direction, such as encouraging the use of public transport, promoting electric vehicles, and optimizing traffic flow to reduce congestion and emissions.

(5) Synergy of policies and regulations

Advances in technology can promote the formulation and improvement of policies and regulations. As traffic prediction technology advances, relevant policies and regulations need to be updated in tandem with it to ensure the healthy development of the technology and the overall interests of society. For example, laws and regulations on data privacy protection, traffic safety standards, and traffic management authority need to be constantly updated to adapt to the changes brought about by new technologies.

By exploring these future directions, we can foresee that intelligent transport systems will play an even more important role globally. With the continuous advancement of technology and in-depth application, intelligent transport will bring more convenience and benefits to city management and residents' lives, while also contributing to the goals of sustainable development and environmental protection. The future intelligent transport system will be data-driven, intelligent and adaptive, and environmentally friendly, and it will be closely linked with urban development to jointly shape a better future.

In conclusion, the application of AI in the field of intelligent transport is promising, and future research will continue to drive technological innovation, solve existing problems, and lay the foundation for building a smarter, more efficient, safer, and sustainable transport system. With the continuous progress of technology and the depth of application, artificial intelligence will play a greater role in the field of intelligent transport.

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