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An Overview of the Research and Development of Networked Highway Toll Collection Systems

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Abstract

The application of computer technology has enabled China's motorways to develop from manual toll collection to the current electronic non-stop toll collection, gradually forming a planned overall road network toll collection mode. In order to improve the efficiency and service quality of motorways, all provinces in China are planning to set up network toll collection systems, which can improve the shortcomings of the old toll collection methods to the maximum extent possible, unify the motorway network as a whole and ensure the smooth flow of vehicles within the network. Based on this, this paper presents a comprehensive account of the research and development of highway network toll collection systems. By introducing the composition and form of highway network toll collection systems, it outlines the construction and development stages of network toll collection systems, focuses on the key technologies in each stage, summarises and analyses the development trend of highway network toll collection systems in the light of the current research status, and outlooks on the future development trend.

Keywords

Highway; Network Toll Collection System; ETC; Overview.

1. Introduction

With the rapid development of domestic social and economic, highway network capacity has gradually failed to meet the needs of traffic growth, urban highway traffic congestion is becoming increasingly serious, traffic accidents and pollution problems are increasingly causing widespread concern in society. From the experience of the world's developed countries in the construction and management of highways, it is difficult to fundamentally solve the growing traffic demand by relying on the expansion of roads and the scale of the road network alone, and it is necessary to use high and new science and technology to transform the existing road transport system and its management system to closely integrate vehicles, roads and users[1]. The use of highway network toll collection system has standardised the traffic order of vehicles at road junctions, improved the safety of toll collectors and facilities at road junctions, and provided material guarantee for civilised services at road junctions. For strengthening the vehicle toll collection management, improve the vehicle toll collection and inspection management level and work efficiency has an important role[2]. As an important part of the highway network toll collection system, the perfection of its function and the depth of the research field have become more and more the need of the times. To a certain extent, the toll collection of motorways affects the efficiency of vehicle passage, therefore, it is of great practical significance to study and analyse the development of motorway network toll collection system.

In the light of these realities, a comprehensive presentation is made on the research and development of connected highway toll collection systems. It firstly introduces the structural components of

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highway networked toll collection systems, secondly introduces the construction and development stages of networked toll collection systems, focuses on the key technologies in each development stage of highway networked toll collection systems, and finally concludes with a summary of highway networked toll collection systems and an outlook analysis of their development trends in the light of the current research status.

2. Overview of the Highway Network Toll Collection System

2.1 System Description

Highway network toll collection system is the use of modern information technology to enhance the level of highway management, to achieve modernization of highway management, to ensure the highway traffic safety and smooth effective measures, has become an important part of the highway intelligent transportation system[3]. In simple terms, highway network toll collection is a network of highways in a certain area, the main line does not set up a toll station, only in the ramp set up a toll station, using a closed toll system, road users only need to receive a card at the entrance, exit payment, you can reach any destination within the road network.

The highway network toll collection system refers to the highly intelligent highway toll collection comprehensive management system which is established uniformly in different sections belonging to different owners in a road network by applying modern traffic control and information management theory, integrating computer network, information transmission, image processing and electronic measurement and control technology, it makes the user who uses this road network only need to execute the toll payment process when entering or leaving the road network in the process of use. The process, when necessary, also need in some intermediate stations such as marker station to execute the relevant process, through the OBU (vehicle electronic tag) or CPC card, and ETC antenna for wireless data interaction, complete the toll collection, realize the free flow sectional billing and charging, and according to the different owners, investment body for settlement clear, thus realizing the highway toll management " A cartoon". It not only facilitates the majority of road users, reduces travel costs, gives full play to the social benefits of the motorway, but also ensures the economic benefits of investors, improves the service level and management efficiency of the motorway toll collection, and is an important part of the national development strategy for the realisation of motorway information and intelligent transportation[4].

2.2 System Components

The general highway charging system can be divided into three parts: lane charging system, toll station system and toll centre system. The highway network toll collection system is divided into four computer network system structures: provincial network settlement centre, section toll centre, toll station and toll lanes. The provincial network charge settlement centre is the core part of the whole network charge system, its main functions are: the management and maintenance of the whole system, data statistics, storage and processing, toll clearing, external data query and retrieval, IC card issuance, management and other functions; the main functions of the section charge centre are the management and maintenance of the section system, the link with the provincial network charge settlement centre, etc.; the charge station is the node of the charge system. It is the most basic charging unit in the network structure of the charging system, and its main functions include managing the charging lanes, receiving, processing and uploading the original charging data, etc.; the charging lanes deal directly with the road users, and its main functions include managing and controlling the lane equipment, collecting and uploading the original charging data, etc.

The highway network toll collection system adopts a hierarchical management approach, and its overall system structure is shown in Figure 1. Each toll station is equipped with manual toll lanes and electronic non-stop toll lanes to charge the vehicles passing through, and submit the relevant data to the corresponding section toll centre. The section toll centre then carries out statistical processing of the data from the toll stations under its jurisdiction and transmits the statistical results of the toll collection situation of each road section to the provincial network toll settlement centre. In this way,

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after the data is counted and reported to the provincial network toll settlement centre at each level, the provincial network toll centre then counts and distributes the benefits to the various highway operating units, while the provincial network toll settlement centre sends the verified toll split results and the toll revenue data of each road section down to each road section toll centre for verification, realising the whole process of network toll collection[5].

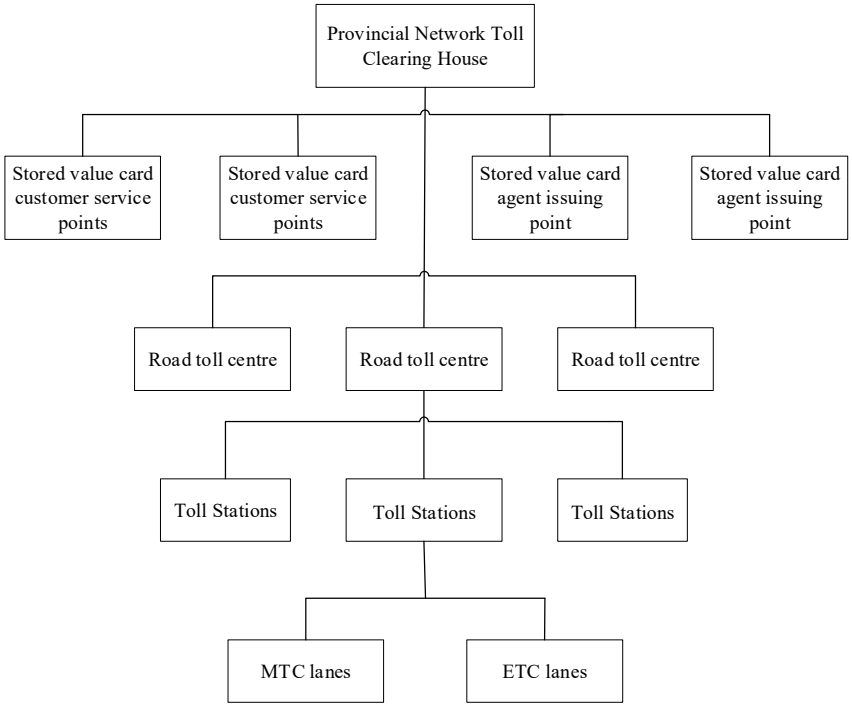

Figure 1. Structure of highway network toll collection system

2.3 System form

The highway network toll collection system can realize both semi-automatic and non-stop electronic toll collection methods.

2.3.1 Semi-automatic Charging System

Semi-automatic toll collection system, that is, MTC system, using automatic billing - manual billing - computer management - TV monitoring, separating the billing and charging procedures, using the pass card for billing at the entrance, and using the stored value card for bookkeeping or cash payment at the exit, this kind of toll collection system belongs to a combined toll collection method, mainly consisting of manual and mixed lane toll collection systems. The manual lane charging system is a semi-automatic charging method, the main facilities include lane control machine, manual card reader, vehicle detector, ticket printer, automatic railing, etc.; the mixed lane charging system adds magnetic card or IC card charging, requiring the driver to hold a valid document and vehicle driver's licence to apply for a payment card at the service outlet, in general, the payment card is divided into two forms: (1) bookkeeping card, this (2) stored-value cards, mainly applicable to units or individuals. Drivers with a payment card can simply swipe their card at the exit or entrance to the motorway, which greatly improves the efficiency of vehicle movement[6].

2.3.2 Non-stop Electronic Toll Collection System

The non-stop electronic toll collection system, that is, the ETC system, is an important component of the ITS system structure of intelligent transportation system, which has wide application abroad and is also a more mature technology developed in the ITS system. Stopping can be directly through the toll station, and the relevant fees will be directly deducted from the card, effectively alleviating the phenomenon of vehicles queuing for payment. ETC technology is an important means to improve the safety and efficiency of existing roads, and is also a growing environmental protection need, the

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system mainly includes vehicle recognition system, central management system and other auxiliary facilities, of which the vehicle recognition system The system mainly includes vehicle identification system, central management system and other auxiliary facilities, among which vehicle identification system includes vehicle-mounted unit OBU, roadside unit RSU and loop sensor, etc. Its main advantages are reflected in the following aspects[7].

(1) Passing efficiency: ETC can significantly improve the passing efficiency of vehicles, especially compared to mobile payment, which not only takes longer to complete transactions (around 0.6s), but also requires higher communication quality of the network. ETC adopts microwave communication technology, which is not restricted by network conditions, and the average passing time is only 0.3s.

(2) Security: ETC itself has a high level of security. Compared with the sweeping code payment method, they have higher requirements on the accuracy and stability of licence plate recognition, and once the licence plate is obscured or defaced, it may affect the charging efficiency. In contrast, ETC adopts two-way authentication technology for smart cards, which has higher compatibility and consistency and higher security.

(3) Path restoration: ETC itself uses microwave communication technology to complete the non-stop toll collection of vehicles, with a restoration rate of up to 99.5% for the path.

3. Development of Connected Charging Systems

3.1 Development of Networked Charging Technology Abroad

Many highways in foreign developed countries are not tolled, so there is almost no research on networked highway toll collection systems. The main highways that are more developed and related to toll collection are the United States, Japan and Europe.

The United States, Japan and European countries have started the research of ETC's innovative technology, highway construction, vehicle identification specification, etc. at a very early stage and submitted the draft of electronic non-stop toll standard to the International Organization for Standardization. The standards proposed by Europe and Japan have been relatively mature and have gained the support of more enterprises[8]. In the United States, electronic non-stop tolling has become a means of recovering highway investment and maintenance costs. The networked electronic non-stop toll collection system operating in the USA is the E-Zpass system, which uses an open toll collection system and constitutes a network of dedicated lanes and mixed lane patterns for toll collectors on duty. In Germany, vehicle tolls are included in the fuel and maintenance tolls. Germany's motorway toll system is a windowless, advanced road toll system which uses a combination of satellite positioning and mobile communication technology to replace the traditional barrier-type toll booths[9]. Prior to 2001, Japan used magnetic card-based toll collection, but from 2001 onwards, Japan began to actively invest in the use of ETC technology, and by December 2012, a cumulative total of over 52 million vehicles, or approximately 70% of the total number of vehicles, had been fitted with dedicated ETC on-board units[10]. Portugal, using the Via Varde electronic toll collection system, a typical European networked toll collection system, with a combination of closed and open toll collection[11].

ETC lanes are operating successfully abroad, each with its own characteristics: lanes are divided into special lane mode and mixed lane mode; duty management is divided into toll collector duty and unmanned duty; bar management is divided into high speed bar and no bar; speed of passage is divided into low speed and high speed passage mode; the method of dealing with toll evasion is divided into on-site processing and image capture time processing. If parking-free and fast-passing services are provided and toll collectors on duty are compressed, the promotion and application of the ETC system will have better prospects[12-14].

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3.2 Domestic Networked Charging Technology Development

The construction of China's toll collection system has undergone the development process of manual toll collection on a single road section → semi-automatic toll collection combined with computer management → fully automatic toll collection, i.e. ETC[15].

Chen Aiying[16] studied the management mode of the uncommon inter-provincial network toll collection and proposed that the ETC network toll collection in the Yangtze River Delta should be distributed, i.e. no unified network toll settlement centre should be established and the three parties of Shanghai, Jiangsu and Zhejiang should be responsible for the settlement of the network toll collection. Through comparison, it is considered that the management system of "one network, two levels of splitting, three levels of exchange and four levels of management" is suitable during the construction and early operation periods of network toll collection, while the management system of "one network, two levels of splitting and three levels of management" is suitable during the mature operation period of network toll collection. ETC technology began to emerge in the 80's, the 90's in use around the world, the technology is developing rapidly, the initial use of magnetic card charges, more disadvantages, the middle of the change to contact IC card charges, as long as the application in public transport charges and other semi-manual charging system, the late the use of non-contact ID card charges, suitable for high-speed movement of objects to identify, the real realization of non-stop charges[17]. Wu Xu[18] compared the highway toll collection methods and divided the ETC system into four major components: automatic vehicle identification system, automatic vehicle typing system, violation capture system and transaction processing system. Zhao[19] analyses the nature of highway tolls and examines the impact that the setting of toll periods can have on the interests of society. Liu Jiehua[20] pointed out the lack of traffic information collection in China's current highway networking system, making the entire road network capacity, traffic safety and other aspects of certain constraints. Zhang Hongmei[21] presented specific licence plate recognition technology for use in networked toll collection systems to prevent cheating. Zhang Xiangmin[22] believes that the problem of highway vehicle toll evasion should be curbed through a variety of audit means, through strict management of the toll collection work into a virtuous cycle. Wang Jiuzeng[23] researched a hybrid lane non-stop toll collection system containing both MTC and ETC functions, which solved the key problems of all-weather reading, masking, sequencing and automatic switching, and greatly reduced the investment of land and other resources in the construction of the ETC system. Xi Shenghua and Liu Yuping[24] also proposed three management modes based on the conditions of ETC networked toll collection: fully networked, electronically networked and combined, solving the traffic bottleneck problem at inter-regional demarcation stations.

4. Key Technologies for Connected Charging Systems

4.1 Vehicle Identification Technology

The key technology of the networked charging system is the automatic vehicle identification system. At present, there exist two kinds of frequency automatic vehicle identification system on the market at home and abroad, one is the automatic vehicle identification system of 902~928MHz of the United States; the other is the automatic vehicle identification system of 5.8GHz which is represented by Europe. From the perspective of the reliability of the system, the choice of 5.8GHz is more in line with the actual situation of China[25]. The most straightforward way to classify vehicles is to weigh them, however, due to the low lifespan and high cost of current vehicle weighing equipment, the practicality is poor. Infrared classification methods are more effective, the technology and equipment are more mature, and products can be purchased and configured directly. The computer vision-based vehicle classification method has gradually moved from the laboratory stage to the actual system, with a high degree of automation, inexpensive equipment, good operability and high reliability, and is the mainstream of future vehicle identification. The identification technology used is microwave non-contact ID card identification technology, microwave non-contact ID card (i.e. OBU) receives the interrogation signal sent by RSU, and sends the control unit for processing by data demodulation,

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through identity confirmation, after password verification, the control unit reads and writes data to EEPROM and after encoding, encryption, and then modulation, and transmits out by antenna. The processing control unit is mainly used for password verification, programming mode check, data encryption and decryption, and to control the read/write operation of the EEPROM, which contains the vehicle ID number, licence plate number, model, driver and other relevant information, and the RSU makes the corresponding operation according to the received ID number and other information to achieve the identification of the vehicle[26]. Automatic number plate recognition technology belongs to the category of pattern recognition and is a technology that uses images or videos of vehicles to carry out automatic recognition of licence plate numbers. The core of its software includes licence plate positioning algorithms, character segmentation algorithms and character recognition algorithms. A complete licence plate recognition system should include several parts such as vehicle detection, image acquisition, licence plate positioning, character segmentation and character recognition. When the vehicle arrives at the image acquisition point, the current video data of the vehicle is collected and transmitted to the computer, and then the data is processed to locate the specific location of the licence plate, and then the character segmentation is carried out on the region of the licence plate obtained from the positioning, and finally the segmented characters are identified and the results are output[27].

4.2 Computer and Network Technology

Computer and network is to realize the highway toll system intelligence and automation of the basic technology, a card highway toll system mainly to regional and provincial multiple highway network toll, must have a high-speed reliable computer network to complete the toll work. Wei Wu analyses and compares the performance of six types of toll collection methods: manual, microcomputer pass ticket, contact IC card, coin, weighing, contactless IC card and electronic toll collection, and believes that a more reasonable and practical toll collection scheme should not only take into account the existing successful technology and experience of the motorway, but also facilitate the transformation of automation and intelligence to the future motorway toll collection system, and make it easy to realize network toll collection. The system is based on a computer network and uses microwave communication electronic toll collection and infrared communication contactless IC card toll lanes to realise networked toll collection. The system is based on a computer network and applies microwave communication electronic toll collection and infrared communication contactless IC card toll lanes to realise network toll collection[28]. In response to the shortcomings of long development cycles and poor maintainability of highway toll collection systems, Xie Ziliang and Zhang Youguang[6] designed and implemented a generalised lane toll collection system based on component and framework reuse technologies, on which developers can carry out secondary development, thus greatly shortening development cycles, reducing development costs and improving reliability and maintainability. Among them, the component technology will object-oriented technology to a higher level, it is to solve the software system operability, scalability, language independence and location transparency and proposed; framework is a greater strength of software reuse technology, its starting point is to reuse similar analysis and design results and architecture on the basis of reuse code, in order to reduce the cost of constructing new software systems and improve software reliability, it is the reusable design of all or part of a software system for a particular application area. The key to connected charging is networking, i.e. the remote transmission and sharing of large amounts of data, which relies on modern communication networks. Its main requirement for the network is real-time and transmission reliability, SDH transmission network is a good choice, combined with the construction status of China's highway communication transmission network and the demand of data communication of toll system, Ma Yue, Su Yanbin[29] analyzed the 3 network transmission technologies SDH, ATM and broadband IP technology adapted to highway communication from the aspects of structure and performance, as well as the comprehensive integration of these 3 technologies models ATM Over SDH, IP Over ATM, IP Over SDH, IP Over WDM, put forward the technical solutions that are more suitable for the networking of highway toll system, and designed the specific contents of network communication management and maintenance.

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For the characteristics of the highway toll system toll data accuracy and reliability is in the first place, so broadband IP technology is a good choice. With the arrival of networked highway toll collection and centralised road network monitoring, IP Over SDH is the preferred choice for highway toll system communication systems and their networking technology, while broadband IP Over WDM technology will be the future development trend for toll systems and traffic-specific communication networks.

4.3 Electronic Toll Collection System

The ETC system is a wireless communication and information exchange between the vehicle-mounted device installed on the vehicle and the antenna installed on the lane of the toll station, and is mainly composed of the vehicle automatic diagnosis system, the central management system and other auxiliary facilities. Among them, the vehicles automatic diagnosis system by the vehicle unit (OBU) also called the transponder or the electronic label, the roadside unit (RSU), the loop inductor etc. The OBU has the vehicles recognition information, generally installs in the vehicle front windshield, the RSU installs in the toll station side, the loop inductor installs in the lane ground under. The central management system has a large database which stores information on a large number of registered vehicles and users. When a vehicle passes through the toll booth, the loop sensor senses the vehicle, the RSU sends out an interrogation signal, the OBU responds and carries out two-way communication and data exchange; the central management system obtains vehicle identification information, such as vehicle ID number, vehicle type and other information and compares it with the corresponding information in the database to make a judgement, and controls the management system to produce different actions according to different situations, such as the computerised toll management system deducting the amount due from the vehicle's The computerised toll management system deducts the toll payable from the vehicle's prepayment account, or sends instructions to other auxiliary facilities to work. Other auxiliary facilities such as: illegal vehicle camera systems, automatic control barriers or other obstacles, traffic display equipment (red, yellow, green lights, etc.) to indicate the movement of vehicles. As the electronic toll collection system has efficient and reliable working efficiency, it must also be equipped with relevant equipment components in its working operation in order to better complete the integrated working method of toll collection and processing. AVI automatic vehicle monitoring is to retrieve vehicle information and owner information to detect, in many data information quickly find the owner information, and then scratch its owner toll. AVC vehicles automatic identification detection instrument installation location, is on the road and road side and so on way to The VES vehicle evasion capture system is used to capture vehicles that do not comply with the toll collection system at the toll station and force their way through, extracting the owner's information or the vehicle's licence plate number as a basis for combating toll evasion in the future[30].

5. Conclusion

To sum up, with the continuous expansion of the scale of the motorway network, higher requirements have been put forward for the operation and management level of motorways. The application of information technology, intelligent technology and computer technology, especially in the context of the continuous development of the Internet, has further improved the operation and management level of motorways. The realisation of networked toll collection is the main manifestation of the networked development and management of motorways, thus better adapting to the needs of modern motorway development in China. The networked toll collection system has greatly improved the efficiency of China's motorway toll stations, and this achievement is gradually covering the whole province and the whole country, so as to achieve the continuous improvement of the efficiency and quality of work in a large area. The scientific, rational and efficient highway network toll collection system is a huge impetus to promote China's modern highways to the direction of intelligent highways, providing a broader development space for the development of traffic roads. However, due to the rapid development of China's highway construction in recent years, this has led to the existence of China's

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highway network toll collection system development time is short, technology and research conditions are not mature and many other problems, in the actual operation, there are often a variety of problems and drawbacks such as ETC card fraud phenomenon and evasion cheating, which brings the consequences of economic losses to the highway operating units, to China's construction The consequences of this are economic losses for road operators and challenges to the building of a civilised and ethical society in China. In addition, the unreasonable design standard of network toll collection and the existence of some problems, in most of China's highway toll collection system, there is no unified technical standards, planning and experience, which has caused the management of irregularities and no strict supervision mechanism, resulting in toll station network toll collection can not be good and fast development.

In view of these problems of the current motorway network toll collection system, in the future development of the motorway network toll collection system, relevant workers must pay attention to the research of relevant technologies, continuously introduce new technologies and new equipment, and formulate unified technical standards and operation specifications for the passage hardware, media, communication, data format and toll collection process of the motorway network toll collection system, so as to make the internal network toll collection area of the motorway highway The conditions for interconnection and data exchange are available within and between regions. In terms of unified standards, these include unified standards for vehicle classification, unified data items and unified clearing house, so as to ensure the safe, reliable and collegiate operation of the highway network toll collection system. In addition, as some provinces of trucks need weighing and billing, the introduction of unmanned weighing and billing system is unrealistic, and this process is usually accompanied by disputes and the existence of problems such as green channel goods still need to be manually checked and released, the combination of electronic toll collection and manual semi-automatic toll collection system will be the new trend of the development of highway network toll collection system, and this combined network toll collection system simultaneously takes into account the manual semi-automatic toll collection system and This combined network toll collection system simultaneously takes into account the advantages of both the manual semi-automatic toll collection system and the ETC system, and can effectively prevent the ETC card scraping phenomenon and fare evasion cheating. The combined network toll collection system uses the electronic label plus the double interface IC card to combine the two, and can achieve comprehensive goals such as improving the efficiency of vehicle passage and improving the intelligence of the toll collection system in the whole road network of the motorway, and this toll collection mode can provide a safe and reliable solution to the problem of prepaid cards for the networked intelligent toll collection system, and can effectively solve the traffic and transportation problems of the towns along the motorway. Traffic and transport problems, promote the economic construction and development between regions, and meet the basic national conditions of China. The process of improving the highway network toll collection system is a long-term dynamic development process. As the problems that have arisen in the system are solved through various measures, new problems may arise as a result of the implementation of these measures, and other measures will be required. However, through continuous problem solving, the system will become more and more mature and continue to improve, thus providing the foundation for the continued development of the social economy.

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