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Application and realization of key technologies in China railway e-ticketing system

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Abstract

Purpose – With the yearly increase of mileage and passenger volume in China's high-speed railway, the problems of traditional paper railway tickets have become increasingly prominent, including complexity of business handling process, low efficiency of ticket inspection and high cost of usage and management. This paper aims to make extensive references to successful experiences of electronic ticket applications both domestically and internationally. The research on key technologies and system implementation of railway electronic ticket with Chinese characteristics has been carried out.

Design/methodology/approach – Research in key technologies is conducted including synchronization technique in distributed heterogeneous database system, the grid-oriented passenger service record (PSR) data storage model, efficient access to massive PSR data under high concurrency condition, the linkage between face recognition service platforms and various terminals in large scenarios, and two-factor authentication of the e-ticket identification code based on the key and the user identity information. Focusing on the key technologies and architecture the of existing ticketing system, multiple service resources are expanded and developed such as electronic ticket clusters, PSR clusters, face recognition clusters and electronic ticket identification code clusters.

Findings – The proportion of paper ticket printed has dropped to 20%, saving more than 2 billion tickets annually since the launch of the application of E-ticketing nationwide. The average time for passengers to pass through the automatic ticket gates has decreased from 3 seconds to 1.3 seconds, significantly improving the efficiency of passenger transport organization. Meanwhile, problems of paper ticket counterfeiting, reselling and loss have been generally eliminated.

Originality/value – E-ticketing has laid a technical foundation for the further development of railway passenger transport services in the direction of digitalization and intelligence.

Keywords E-ticket, Ticketing system, Passenger service, PSR, Dynamic QR code

Paper type Research paper

1. Introduction

Over the past 2 decades, China railway ticketing system has gradually developed from a single ticket sales service system in stations with a pure ticket selling business to the world's

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largest integrated ticketing system covering online services (i.e. the 12306 online ticketing system, including its website and APP) and more than 3,000 offline passenger stations, providing ticket sales, extended services, marketing decision-making and other services. With the development of the ticketing system, the transformation of train tickets has gone through four generations: hardboard paper ticket, soft paper ticket, magnetic paper ticket and paperless ticket. As the railway passenger tickets have been made of paper materials for a long time, the inherent problems of such practice have become increasingly prominent with the increasing amount of passenger year by year. Tackling these problems effectively makes a significant impact on railway passenger service quality. At present, problems caused by paper tickets are mainly manifested in four aspects. Firstly, different ticketing systems cause inconveniences for passengers. Due to the diversified ticketing channels, various ticket types coexist at the same time consisting soft paper ticket, magnetic paper ticket and e-ticket. It is difficult for passengers to fully understand the business rules for different ticket systems which are generally similar but with distinctions and specificities, so it is difficult for passengers to fully understand them. Therefore, various problems are likely to occur in ticket verification, refund and other scenarios; and this phenomenon will not only degrade the passenger experience, but is also unfavorable for passenger transportation organization. Secondly, there is a huge consumption of ticket paper, which is inconsistent with the concept of green travel. For a long time, it has become a stereotype that railway travel comes with paper tickets. In addition, limited publicity of new railway service measures sees a low rate of passengers' willingness to try new Internet e-tickets, so that passengers are still used to getting paper tickets before traveling, thus invisibly increasing the total travel time of passengers and the social cost of travel. Third, paper tickets are easy to be lost, and the handling process is cumbersome. In 2018 and 2019, 1.6 million people have lost or reissued their train tickets every year. However, due to the complicated handling process of ticket loss and reissuing service and poor passenger experience, it is easy to cause disputes and complaints, which will negatively impact passenger travel experience. Fourth, failure to effectively eliminate the illegal dealings of tickets and sales of fake tickets not only seriously endangers the legitimate rights and interests of passengers, but also has a serious impact on the normal railway transportation activities.

Analysis shows that the main reasons for the above issues are as follows: the ticketing system has a long history of development, and the upgrading of ticket-making equipment cannot be carried out in a one-size-fits-all manner, so it is inevitable that multiple ticket types coexist. Also, traditional paper tickets concurrently bears the weight of three attributes: railway transport contract, travel voucher and reimbursement voucher. The loss of paper tickets means that the three proofs are lost at the same time. Therefore, passengers who have lost their tickets are allowed to continue going on their trips, with a deposit equaling to the ticket price before obtaining the ticket according to the rule and procedure formulated by the railway department for ticket loss report and reissuing. Passengers are required to contact the train conductor for a passenger transportation record when getting on the train. After arriving at the station, they can take back the deposit after returning the passenger transportation record issued by the train conductor and the reprinted ticket. The whole process is complicated and troublesome, so that it is very likely to cause misunderstandings and disputes. In addition, in terms of anti-counterfeiting, although the railway department has done a lot of work, the paper ticket itself has weak anti-counterfeiting performance, which provides an opportunity for criminals to forge or alter tickets, thus deceiving passengers and disturbing the transportation order. As a result, it is an inevitable choice to learn from the successful experience of other national civil aviation and railway sectors in ticketing system innovation, study the key technologies for the transformation from paper tickets to e-tickets and the supporting upgrade schemes of the ticketing system at the architecture level, therefore eliminating the restrictions of paper tickets on the improvement of passenger service quality and service level.

2. Literature review

The concept of e-ticket first appeared in the civil aviation industry, and it is a way to realize ticket sales, passenger boarding and related services without paper tickets (Ma, 2005). E-ticket does not mean "no ticket", and it is in essence an electronic image of ordinary paper ticket. At present, e-ticket is available in airlines around the world, and its remarkable convenience and security has become an important reason for passengers to choose it. Since the e-ticket service has been available in China's civil aviation industry, passengers can buy tickets through the Internet, print boarding passes at the airport and then check in. Business passengers can obtain travel itinerary for reimbursement by means of self-service printing, counter preparation or agent mailing. The electronic transformation of civil aviation tickets has well solved problems of paper tickets. The electronic billing system "Billing and Settlement Plan" (BSP) of China's civil aviation industry was built in 2004. Based on the agent distribution system, flight control system, departure system, settlement system and BSP data processing system (Zhou, Jia, & Huang, 2005), the system realizes the electronic flow of data among booking, departure and settlement systems. The mainframe technology was initially adopted for the system, and the core service system was then gradually migrated to a "cloud computing" service platform (Peng, Yang, & Hu, 2017). In order to meet the growing demand for online ticketing, the machine learning technology has been introduced into the civil aviation ticketing system to dynamically decide the caching strategy according to users' query behavior (Yao, Zhou, Li, & Yang, 2017; Qiu, Wan, Lin, Liu, & Yao, 2017), reducing the direct query flow of the background host system, and a self-developed data synchronization mechanism has been used to realize the rapid data synchronization between the host system and the external open system (Jia, Yan, & Zhang, 2011), thus reducing the load of the core system; in view of the problem of high concurrency under the condition of large passenger flow, a server architecture optimization scheme (Li, Tian, & Ni, 2016)[based on a phased event-driven architecture and a dynamic load balancing strategy (Tian, Ni, Ding, & Wang, 2016) are proposed at the system architecture level to improve the processing performance and stability of the system. In terms of the data structure of e-ticket, a new passenger-centered order data structure and a brand-new order management system (Liang, Huang, & Du, 2017) have been built by integrating the original data items related to passenger orders to help improve the service efficiency and quality of e-ticket. Among other national railways, German railways have realized the electronic ticketing in its early stage. Its online ticketing platform construction was started in 1997, and e-tickets sale was officially launched in 2012 (Fang, 2020). Since then, passengers have traveled with e-ticket quick response (QR) codes.

From a comprehensive point of view, both civil aviation systems and other national railways choose the development direction of replacing paper bills with e-tickets. The domestic civil aviation electronic billing system was built early, so that a lot of experience has been accumulated in the process of research and development and practical application, which may provide some reference for the railway industry. However, there are great differences between China's railways and civil aviation in transportation organization mode, target passengers and existing system architecture. Therefore, in the process of reconstructing service process around e-ticket, it is necessary to find a path suitable for the characteristics and the needs of China's railways. This paper studies the key technologies and system realization scheme for the comprehensive application of railway e-ticket based on the actual situation of railway passenger transportation in China.

3. Definition and characteristics of railway e-tickets in China

Railway e-ticket is a kind of electronic data stored in the railway ticketing system, a voucher of the railway passenger transportation contract in the form of electronic data, and an electronic form of traditional paper ticket transport contract attribute, and it carries the information of relevant elements associated with railway passenger transportation services. Its features are mainly reflected in the following aspects.

(1) Information-based whole-process service. Information-based service is made available for passengers in the whole process from buying ticket, check-in, waiting for train, boarding train, check-out to transfer and so on. It is not necessary for passengers to print paper tickets after ticket purchase; instead, they simply go through the route involving identity verification, check-in, boarding, check-out and ticket checking on the train with the valid identification (ID) documents for ticket purchase. The ticketing system identifies the validity of the corresponding e-ticket according to the ID card information. The electronic tickets and information-based whole-process service can effectively eliminate the risks of ticket loss, damage and counterfeiting, and completely solve the problems related to paper tickets.

(2) Self-service ticketing. Passengers with readable ID documents, such as the second-generation ID card, Hong Kong/Macau/Taiwan resident residence card and e-passport, can go through ID document and real-name ticket inspection for check-in and ticket checking for boarding, check-out at the station, and obtain travel information, apply for ticket changes, and print reimbursement voucher on self-service equipment. Passengers who have completed the identity verification on 12306 can directly use the "check-in QR code" in the APP to check in. Passengers with unreadable ID documents can scan the ticket purchase information sheet on semi–self-service equipment, and manually verify the ID documents to complete the formalities.

(3) Integrated online and offline services. Online and offline channels are linked, and service barriers between different channels are broken up, and thus railway e-tickets bought from one channel are valid in all other channels. E-tickets purchased via the 12306 online platform can be changed and refunded at station windows; e-tickets purchased at station windows or on ticket vending machines (TVM) can also be changed and refunded on the 12306 online system.

4. Key technologies of railway e-ticketing system

As a new ticketing system for railway passenger transportation, e-ticket-related services should adopt a centralized processing mode as far as possible to reshape the passenger service process, improve service handling efficiency and reduce system complexity. However, in the process of centralized processing, the problem of scattered data storage and inconsistent structure of existing service systems should be solved first. Secondly, it is necessary to solve the problem of quick query of massive travel information under the conditions of large passenger flow and high concurrency since the data is stored in a centralized manner. Finally, new technologies should be introduced to change the traditional service handling mode and provide passengers with more convenient and safe travel services.

4.1 Synchronization technology under distributed heterogeneous database system

The ticketing system is simultaneously a centralized and a distributed system. Different types of databases and file systems are used in different application scenarios under the distributed architecture, featuring a mixed deployment state of multiple databases and file systems (Li, Yan, Zhu, & Dai, 2017). Therefore, it is necessary to synchronize data among multiple subsystems to realize centralized storage of key service data, and meet the needs of cross-channel ticket changes and quick ticket checking. Consequently, the heterogeneous database synchronization technology across complex and distributed environments such as relational database, nonrelational database, memory database, big data processing platform and distributed file system is studied and designed. The data synchronization process is shown in Figure 1. In the figure, Sybase, PostgreSQL, Oracle and MySQL are commonly used database types in the ticketing system. The acquisition modes for different databases include Sybase database console commands (DBCC), PostgreSQL write-ahead logging (WAL), Oracle change data capture (CDC) and MySQL Binary Log. The acquired data is transmitted by the message middleware KAFKA. General data acquisition consumer programs access different databases via a common database access driver (java database connectivity, JDBC). Oracle call interface (OCI) is used to access the oracle database; for the Sybase database, batch data import is realized by batch loading method (bcp command); for the PostgrSQL database, batch data import is realized by batch loading method (copy command). Data acquisition, data transmission and data loading services are all based on containers to realize rapid deployment and high availability. The containers are Docker containers (the mainstream open source application container engine); Kubernetes toolset is used as the container management tool; services are developed based on SpringMVC application framework.

Data synchronization technology under distributed heterogeneous database incorporates the operations of data migration, real-time data synchronization, regular data synchronization, file import and export among various databases into a unified platform for management to realize a consistent data synchronization process and a standard data transmission format. Data synchronization mainly includes the following three steps.

(1) Data acquisition. The acquisition mode is classified into local mode and remote mode. The local mode has an advantage of fast speed and yet due to the decentralized program management, and it is required to install an agent in the production system. The remote mode has moderate speed, and the software configuration in the environment with high availability is more complicated than that in the local mode. However, the centralized management of programs in the remote mode is simpler and has less impact on the production system, so it is more suitable to be used as the data acquisition mode in the distributed environment. In addition, both full-scale acquisition mode and incremental acquisition mode are supported by data, and the operation parameters such as the number of threads and the size of the data block acquired can be flexibly configured according to the actual production.

(2) Data transmission. Data acquired from the source library is reliably transmitted by the middleware KAFKA. A cache is added between each acquisition program and the transmission middleware to improve data transmission efficiency, so that in the case of alternate operation of multiple data sheets, the batch sorting operation of data can

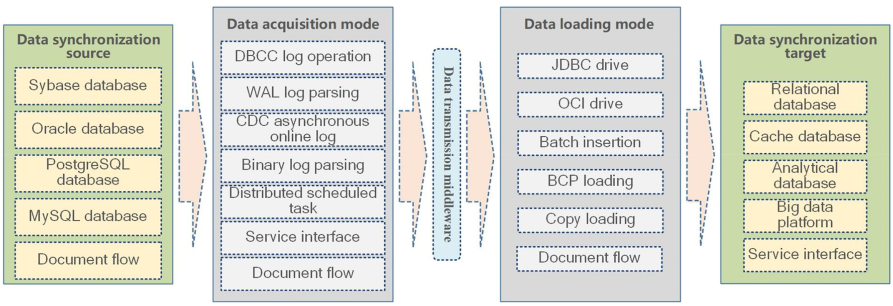

Figure 1.
Heterogeneous database data synchronization process

be completed to realize the synchronous data transmission to the specific queue of the message middleware.

(3) Data loading. Data loading is an operation to copy data from the source database into the target database. This operation is limited by the throughput performance of the input/output of the operating system and the loading performance of the target database, and it is generally the bottleneck of data synchronization. Several key technologies are used in the study to improve the efficiency of data loading. For example, different connection modes and session levels are configured for each database; the intelligent multithread loading mode is adopted, the execution threads are automatically allocated according to the type of structured query language (SQL), the primary key and the unique key are used as the splitting rules, and the data is loaded with the method that threads are allocated by hash modulo, so as to improve the parallel processing capability.

4.2 Grid-oriented PSR data storage model

At present, passengers' travel demand is developing toward a diversified direction; the demand of extended services will appear increasingly in passengers' travel bookings in the future. The diversity of passenger services also determines the complexity of the core transaction data structure. In order to standardize the relationship between different services, simplify the service handling process and reduce the comprehensive load of the system, it is necessary to organize a passenger-centered data structure around the content of passenger travel services to form a complete passenger service record (PSR) data structure to support passengers' personalized service needs and centralized service handling requirements.

PSR data is stored independently, and its data model is of grid storage structure distributed horizontally and vertically as shown in Figure 2. The horizontal data is based on the passenger's ticket, and each passenger's ticket corresponds to one piece of data, which contains multiple preset grids. In the distributed ticketing system environment, the heterogeneous database system synchronization technology synchronizes the key data in the ticket and the extended service order to the preset grids. The vertical data is used to record the process information of each service change, and each change of service will produce an individual record. However, for the horizontal data, only the final state of the changed service will be kept. Organizing and managing passenger travel data in this way can realize the centralized storage of key data of various travel services and the centralized display of the final state, as well as the backtracking of the service change, making it possible to process hundreds of millions of transaction requests per day in combination with the high speed data access technology under high concurrency condition.

In the passenger-centered service process, passengers only need to provide their ID number or the order number to complete the retrieval of PSR data and obtain ticketing information and various extended service information. When handling such services as ticket refund and change, it can be quickly confirmed that whether it is necessary to change associated services, such as Railway Passenger Accident Insurance, meal order and booked shuttle service, for passengers at the same time according to the horizontal data in the PSR data model, so that a large number of invalid query service requests to other service subsystems by polling can be avoided, thus simplifying service handling processes, improving service handling efficiency and reducing system resource consumption.

4.3 High speed access to travel information under high concurrency condition

The highly concurrent data query demand under the condition of tens of millions of passengers per day makes the ordinary relational database unable to effectively support the

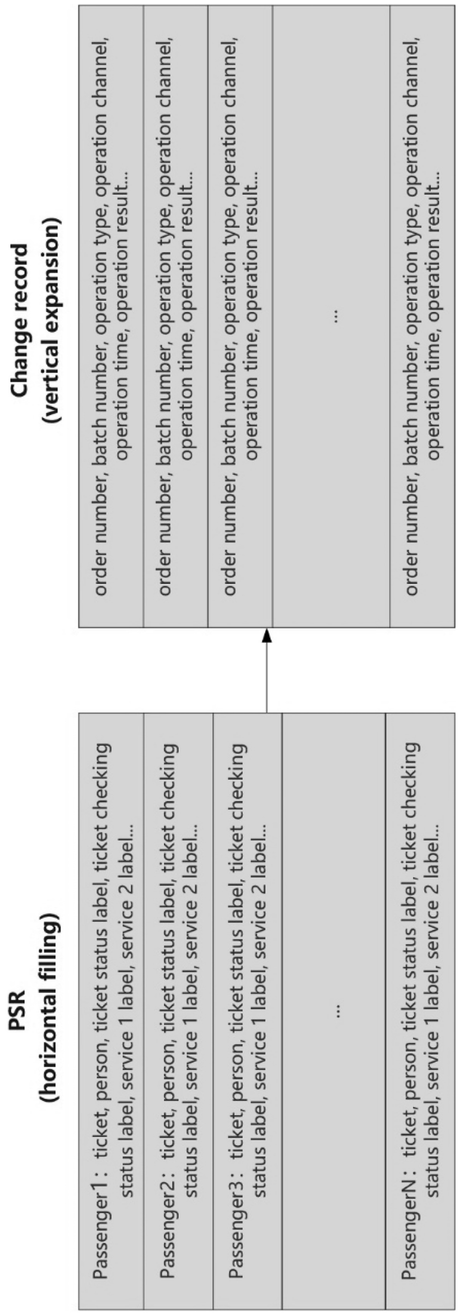

Figure 2.
Grid storage structure of PSR data distributed horizontally and vertically

huge access to massive PSR data. In this study, based on the experience of processing access requests under massive data in the process of online ticketing (Yang, Wang, Mei, & Zhu, 2015; Zhu, Wang, & Zhang, 2014; Mei, Yang, Fan, & Feng, 2018; Zhou & Wang, 2018), the nonrelational database and the distributed storage and virtualization technology are used to build PSR clusters to realize the efficient handling of omnichannel ticket selling, refund, change, checking, verification and all kinds of extended services.

Each PSR cluster is mainly composed of data query and data storage, as shown in Figure 3. Data query is based on microservice architecture (SpringCloud) solution, and each microservice instance is stateless and runs independently in its own process. Lightweight communication mechanism is used among microservice instances. The data is stored in an open source distributed memory database (Remote Dictionary Server, Redis). There are multiple Redis clusters in a PSR cluster, and each Redis cluster is composed of multiple Redis groups. The rate of flow among different Redis clusters can be allocated by percentage; and the service switching between clusters is supported. PSR data is stored in different groups according to the hash of key fields. During the process of data query, PSR information is searched from the corresponding groups according to the hash of query fields. Data is loaded

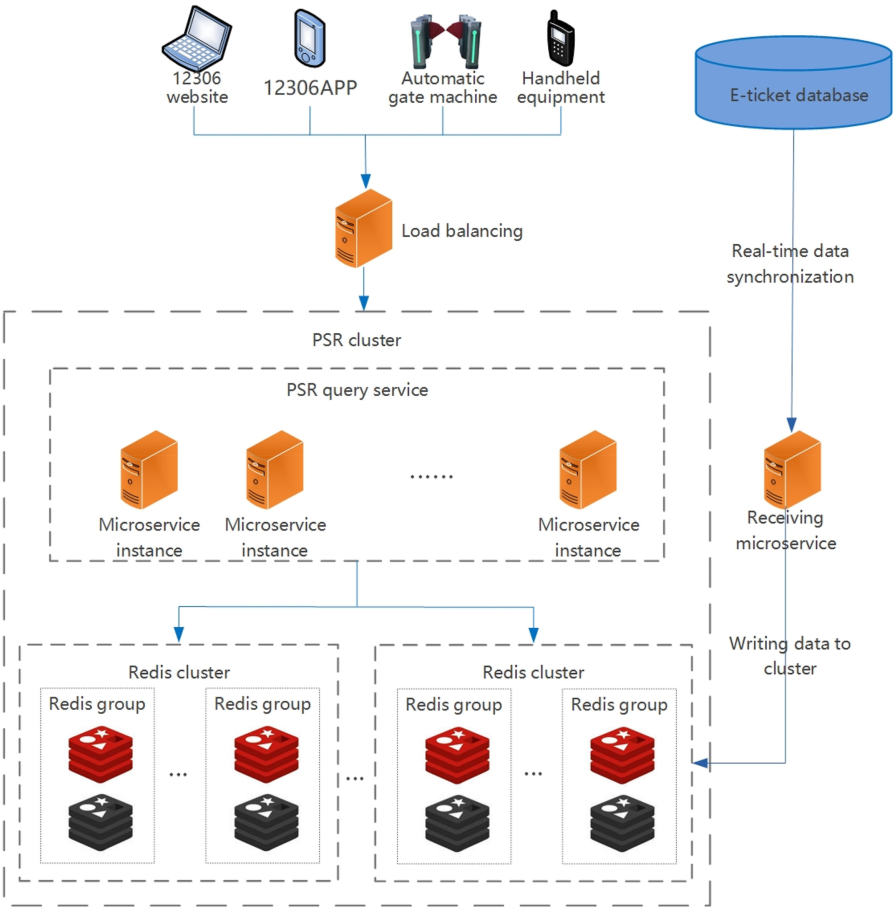

Figure 3.
PSR cluster structure

into the memory when Redis cluster is started. A single data query can be completed within 1 ms. For e-ticket checking, the PSR data needs to be accessed many times, and the total query time is about 2–5 ms. To avoid accidental data loss, Redis writes the data in memory onto the hard disk asynchronously, so as to realize the persistent storage of data and data recovery after an abnormality occurs.

4.4 "Cloud-terminal" linked face recognition technology

Railway face recognition technology has solved the problem of automatic verification of "person-ID document" consistency in the process of self-service real-name verification for check-in (Jia, Dai, Xu, & Su, 2018; Zhang & Li, 2018). The Railway Department has carried out a lot of research and optimization work on face recognition algorithms in different scenarios (Jing, Yan, Dai, & Li, 2019; Dai, Yan, & Jing, 2020; Yi, Zhu, & Jing, 2020; Sui, Yan, Dai, & Jing, 2021) to tackle the problems of face recognition for e-ticket verification in complex railway scenarios, such as the camera backlighting affected by the location of the gate machine, the difference between the image of a real person and the picture on the ID document, and the low performance of the existing gate machines. A complete set of face recognition algorithms has been formed, including lightweight face detection, face recognition, living body detection, face multiattribute detection and other algorithms on the client side, as well as high-precision face recognition algorithms on the server side that can be used in 1: N face recognition scenarios (that is, with the face recognition technology, identity whether the current person exists in the database with a number of N people). The core face recognition algorithm is integrated with currently popular cutting-edge algorithm theories in the field of face recognition, such as Sphereface (Liu *et al.*, 2017), Additive margin (AM)-Softmax (Liu, Wen, Yu, & Yang, 2016), CosFace (Wang *et al.*, 2018) and ArcFace (Deng, Guo, Xue, & Zafeiriou, 2019), and the railway face recognition algorithm is trained with the loss function of various intervals as seen in Equation (1). The algorithm can achieve an accuracy of 99.87% in the test with internationally accepted face recognition dataset (labeled faces in the wild, LFW), and it can reach an accuracy of 98.10% in the railway standard dataset test at a false recognition rate of 1‰.

$$L = -\frac{1}{N}\sum_{i=1}^{N} \lg \frac{e^{s\left[a\cos\left(b\theta_{n_f}+m\right)+c\right]}}{e^{s\left[a\cos\left(b\theta_{n_f}+m\right)+c\right]} + \sum_{j=1,j\neq y}^{n_f} e^{s\cos\theta_i}} \tag{1}$$

where L is the loss function; N is the number of samples in a single batch during training; s, a, b, c and m are hyper parameters, that is, parameters that need to be manually adjusted during training; n_f is the number of categories of face data during training; y is the category of the current sample; θ_{yi} is the vector angle between the current sample and the label; θ_j is the vector angle between the current sample and other samples.

A face recognition "cloud" service platform, including public algorithm service, terminal management, platform monitoring and other functions, is further constructed based on the self-developed face recognition algorithm model to empower the face recognition services of various terminals in different channels. As shown in Figure 4, the "cloud-terminal" linked face recognition application structure covers "cloud" service, front-end processor and "terminal" device.

(1) The private service cloud for railway face recognition is deployed in China State Railway Group Co., Ltd. (hereinafter, CHINA RAILWAY) (Li, Zhu, Yan, Dai, & Hou, 2021) to realize the functions of algorithm management, algorithm training, version management and monitoring, etc.

(2) Front-end processors for face recognition access are deployed in CHINA RAILWAY and railway administrations to provide transparent online and offline service access

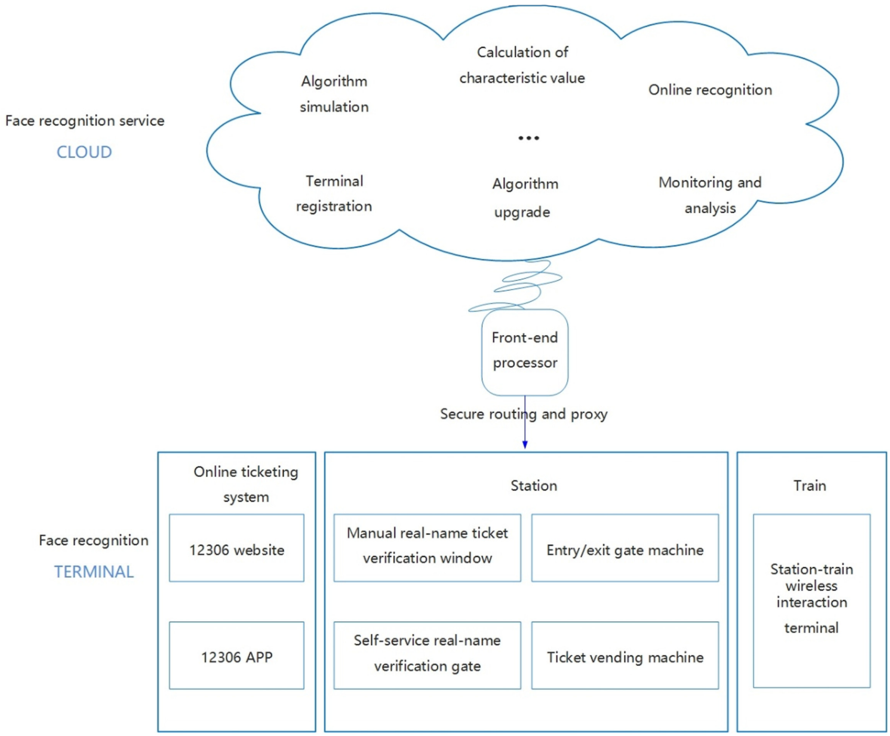

Figure 4.
"Cloud-terminal" linked face recognition application structure

such as application routing and data cache, and automatically distribute the centralized and optimized algorithm to all kinds of terminals in the station in time after the training of the new face recognition algorithm is completed, so as to realize the "cloud-terminal" linkage and ensure the continuous improvement of face recognition service efficiency and accuracy.

(3) The face recognition terminal algorithm driver software is deployed in mobile terminals, station windows, gate machines and other devices to provide terminal applications with standard interface services such as face image acquisition, characteristic value calculation and image recognition. It has the functions of self-registration, self-updating, automatic status reporting, etc., and realizes unified monitoring and management of face recognition algorithms. Meanwhile, it has the security reinforcement capability to prevent the terminal algorithm driver software from being tampered with or cracked.

4.5 Dynamic QR code technology with two-factor authentication

In view of the advantages of low learning cost and high accessibility of mobile phone QR code, the Railway Department has designed the QR code as one of the forms of e-ticket (Li, 2020). Considering that the QR code is manifested as an image, the Railway Department needs to encrypt its content securely, and update its style dynamically according to the time factor to make it a safe carrier of the valuable bill, and to meet the demand of efficient and accurate verification in all travel scenarios, so as to protect the QR code against forgery, piracy and illegitimate spreading. In this paper, the QR code subjected to two-factor authentication and dynamically updated by time is defined as the e-ticket identification code. The e-ticket identification code generation and decoding process is designed as shown in Figure 5. The green boxes represent the modules and services covered by the e-ticket identification code subsystem; the light blue boxes represent the existing services and applications of the ticket, the dark blue boxes the third-party nonticketing platforms, and the orange box the ticketing system background service.

The scheme for the generation and decryption of e-ticket identification code is briefly described as follows.

(1) The e-ticket identification code subsystem is deployed in the ticket network of CHINA RAILWAY to realize functions including key management, cryptographic algorithm management, terminal management and service monitoring, and provide QR code generation service for e-ticket issuing.

(2) The core of security lies in the key. Two-factor authentication technology of the highest level is used for the QR code generation service. Each user has two keys for signature and encryption respectively. The keys are bound with the passengers' 12306 accounts and device numbers, and the user's private key is encrypted and stored in a trusted storage area of the mobile device. The two keys are updated regularly according to different security policies to ensure the security of the encrypted QR code information.

(3) The e-ticket identification code has time attribute, including dynamic update time and validity period of platform data. During the validity period of the platform data, the mobile terminal generates the offline QR code regularly according to the timestamp and the private key in the safe area, making it impossible to intercept and copy the QR code.

(4) In the station-level ticketing system, all terminals that can read QR codes are configured with security modules, which are bound with the terminals and subject to centralized authorization management, thus providing service for offline decoding of e-ticket identification codes.

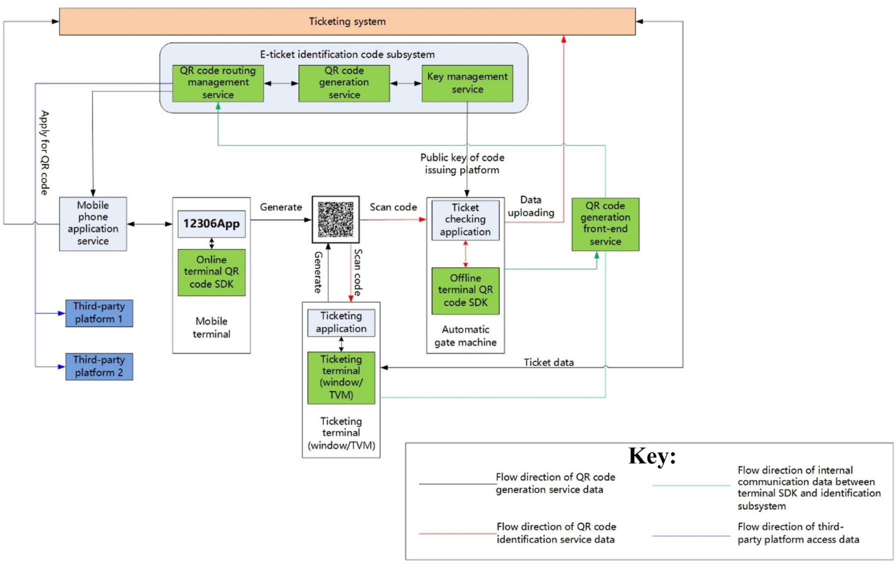

Figure 5.
Application data flow diagram of e-ticket identification code

5. Upgrade of ticketing system architecture

China railway ticketing system is the core supporting platform for railway passenger transportation and service. Since 1997, the former Ministry of Railways has started to organize the R&D and pilot application of computer-based ticketing. After 6 major stages of development, remarkable achievements have been obtained, including the transformation of in-station ticketing from manual operation to computer operation, Intranet ticketing among railway administrations, nationwide online ticketing, centralized management of train seats by the railway department and automatic adjustment of ticketing organization strategy, as well as meeting the development needs of passenger transportation marketing and financial settlement, thus realizing the digital improvement of railway ticketing business. An online ticketing system covering all stations in China has been initially established after the iterative development of the first five versions. The system is mainly deployed by the Ministry of Railways and railway administrations in local stations (Liu, 2001; Wang & Liu, 2001), and provides services for passengers via offline channels such as station ticket office, TVMs and ticket agents.

In 2011, the service channels of the ticketing system were further expanded, and the 12306 online ticketing system was launched to further solve the problem of passengers' difficulty in purchasing tickets and meet the demand of rapid development of railway passenger transportation. The e-tickets served passengers for the first time and were available for some high-speed railway lines, allowing passengers who purchased tickets online to travel without ticket collection. At present, the 12306 online ticketing system is mainly deployed in the first and second production centers. It is necessary to upgrade the system architecture to realize full application of e-ticket in the whole process of passenger travel and meet the practical application requirements of key technologies.

5.1 Core requirements for architecture upgrade

The upgraded system architecture needs to meet the three essential requirements of compatibility, scale and quality.

(1) Compatibility requirements. A variety of services such as e-ticket sale and change and extra service booking are made available on the 12306 online ticketing system, with the annual average ticket sales accounting for more than 80% of the total ticket sales. The sales of China's railway tickets via online and offline channels are shown in Table 1. It can be seen from Table 1 that although the proportion of tickets sold via offline channels decreases year by year, the total number of tickets sold and the corresponding number of passengers remain large. The architecture upgrade scheme should first meet the compatibility of basic services available on offline channels such as ticket sale, refund, change, checking and verification after the transformation from paper tickets to e-tickets, so as to minimize the impact on passengers' travel and on station staffs' workload. Also, it has a great significance to ensuring the compatibility of e-tickets sold on different channels, eliminate the service gap between different

Year	Online ticket sales/100 million pieces	Offline ticket sales/100 million pieces	Proportion of offline services/%
2020	22.56	4.55	16.78
2019	35.67	8.30	18.87
2018	31.07	9.09	22.63
2017	24.59	10.55	30.03
2016	19.48	12.53	39.14

Table 1. Changes in sales of China's railway tickets via online and offline channels

ticketing channels, meet the needs of omni-channel sale and cross-channel change of e-tickets, and reduce the number of round trips for passengers to and from stations to handle business.

(2) Scale requirements. In 2018, the total annual railway ticket sales exceeded 4 billion for the first time, and it is still growing at an annual growth rate of more than 10% (except 2020 due to the impact of the pandemic). Therefore, the architecture upgrade design scheme should be able to meet the needs of basic ticketing services (ticket selling, change, checking and verification) in the next 5 to 10 years, and support horizontal expansion to improve service capacity, so as to meet the needs of expanding passenger transport scale.

(3) Quality requirements. After the centralized storage of e-ticket data and centralized handling of businesses are realized, the ticketing system should have much higher service quality, and meet the quality requirements of efficient implementation and stable service, and important functions should have complete emergency response capabilities.

5.2 Architecture upgrade design scheme

The study on the upgrade of the ticketing system architecture mainly focuses on the application and deployment of key technologies in the process of omni-channel ticket sale, cross-channel ticket change, efficient ticket checking and verification, and the application of e-tickets. The architecture upgrade scheme of the ticketing system is shown in Figure 6.

On the basis of the existing architecture of the ticketing system (Zhu, 2012), the core parts of the upgrade of the ticketing system architecture are located in the 12306 online ticketing system and the railway bureau-level ticketing system, which are used to store the data of e-tickets sold via all online and offline channels, and provide data services for passengers check-in and service change. The system architecture upgrade covers the following aspects.

(1) Dual-center deployment. Relevant equipment is deployed in the dual centers of the existing ticketing system in the same city to ensure high availability of e-ticket service. Private network is used for high speed data synchronization between individual centers. Each center has complete e-ticket data. Once one center fails, the other can undertake all services, thus realizing data-level disaster recovery.

(2) Build a centralized e-ticket cluster across all railway bureaus. A new offline e-ticket cluster is built to store the data of e-tickets sold via offline channels such as station ticket offices and TVMs, so that the data originally stored in the servers of stations or railway administrations can be stored in a centralized manner. Based on the consistent hashing algorithm, the cluster evenly stores the data of tickets sold at different stations and ticket offices/TVMs in different nodes in the cluster, so as to balance the pressure among different service nodes and prevent overloading individual nodes. The offline e-ticket cluster and the original online e-ticket cluster used to store the data of e-tickets sold on the 12306 online ticketing system jointly form the e-ticket cluster across the whole railway to centrally store all the data of e-tickets sold through all channels, providing data support for cross-channel e-ticket change and laying a foundation for the integration of online and offline services.

(3) Create new PSR cluster. The PSR cluster centrally stores the key information of passengers' journeys, and realizes efficient query under massive data through the comprehensive application of microservice architecture (SpringCloud) and Redis database. With the growth of data storage and user access, the PSR cluster can also continuously meet the needs of future business development through horizontal expansion.

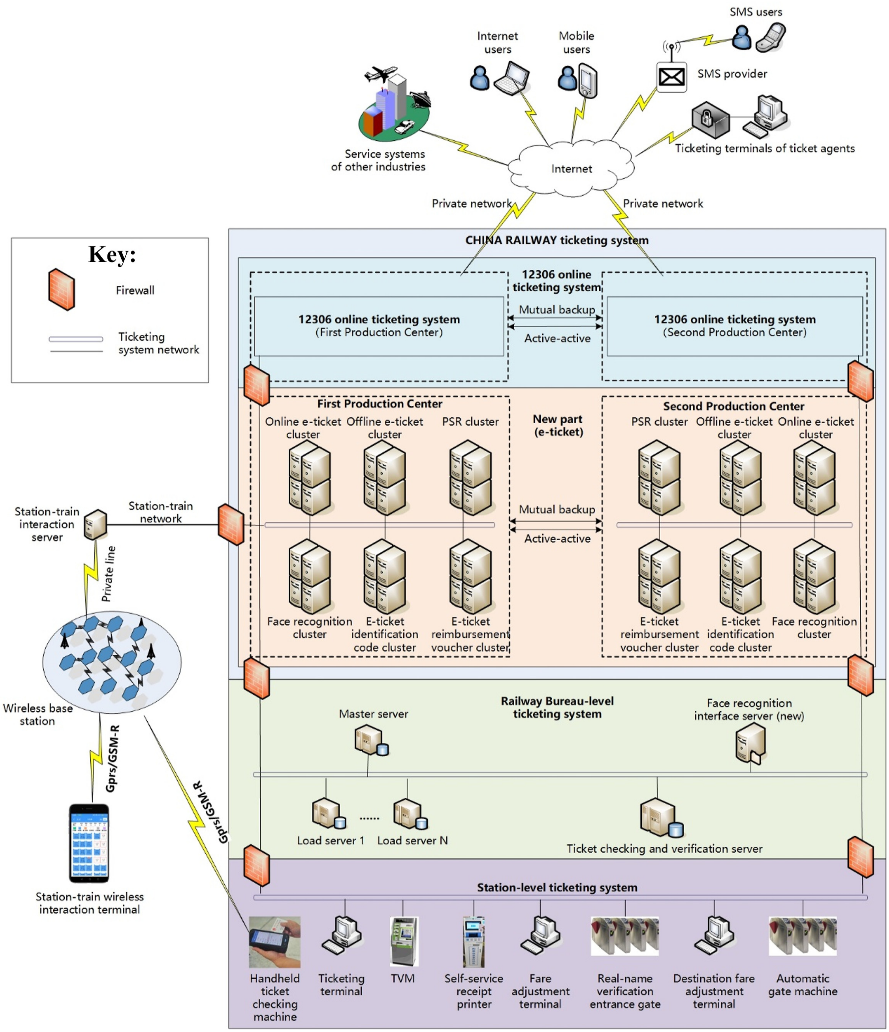

Figure 6.
Upgraded ticketing system architecture

(4) Create new face recognition cluster. The "cloud-terminal" linked face recognition service and the management mode of unified access, unified authentication and unified control of various terminals allow passengers to safely perform identity authentication and self-service in different channels based on unified face recognition algorithm, providing technical support and security guarantee for all-service self-service handling.

(5) Create new e-ticket identification code cluster. All channels are provided with e-ticket identification code generation and online decoding service to ensure the universality and security of QR code.

(6) Create new e-ticket reimbursement voucher cluster. The function of generating and downloading electronic reimbursement vouchers for railway tickets is provided for

passengers who need to print post-travel reimbursement vouchers. At the initial stage of the system construction, the existing ticket paper is temporarily used to print paper reimbursement vouchers for passengers.

(7) Upgrade the railway bureau-level ticketing system. Face recognition interface servers are added to provide the update service of the latest face recognition algorithm for the real-name verification at the automatic gate.

(8) Upgrade and reconstruct ticketing-related systems at stations and on trains. Additional real-name face recognition verification gates are provided; station ticket offices and ticket vending equipment are renewed; all kinds of terminal software in the station covering ticket sale, refund, change and checking and real-name verification are updated; the e-ticket selling, change, checking and verification functions are supported; the station-train wireless interaction terminal software is updated to realize on-board e-ticket verification.

6. Pilot and application results

At the end of 2018, CHINA RAILWAY organized the pilot application of e-ticket on Hainan Island-looping high speed railway (HSR), validated various key technologies of e-tickets, and obtained positive results in the pilot work. In 2019, the upgrade of the ticketing system architecture was completed, providing a strong support for the subsequent large-scale promotion and application of e-tickets across the whole railway. By the Spring Festival travel rush (a period of travel in China with extremely high traffic load around the time of the Chinese New Year) in 2020, the e-tickets have been fully applied at the stations of high-speed trains and multiple unit (MU) trains nationwide; in June 2020, the e-ticketing service was introduced on conventional railway lines, and the transformation from paper tickets to e-tickets for the ticketing system of passenger trains in China was also completed.

At present, passengers can travel by e-tickets in more than 3,000 passenger stations in China. The e-ticketing service can not only provide paperless and intelligent travel services for passengers, but also improve the efficiency of railway passenger transportation organization, reduce the operation costs as well as reducing the time for passengers to pass through automatic ticket gates (from the previous $3.8\ \mathrm{s}\cdot\mathrm{person}^{-1}$ to $1.3\ \mathrm{s}\cdot\mathrm{person}^{-1}$). In 2020, a total of 2.337 billion e-tickets were sold nationwide, saving 1.805 billion pieces of ticket paper; the cost for purchase and maintenance of equipment has been greatly reduced thanks to the cancellation of the paper ticket processing modules. Since the ticket refund and change services have been made available among all channels, a large number of passengers choose to handle the processes by themselves via online platforms. Table 2 shows the number of ticket refund and change services via online and offline channels in China. It shows that the proportion of offline ticket refund and change services has dropped sharply from 29.56% during the peak period to 12.40%, which greatly reduces the service handling pressure of railway ticket counters while shortening the waiting time of passengers.

Table 2. Number of ticket refund and change via online and offline channels in China

Year	Online ticket refund and change/ 100 million pieces	Offline ticket refund and change/ 100 million pieces	Proportion of offline services/%
2020	5.60	0.79	12.40
2019	6.91	1.35	16.36
2018	5.79	1.40	19.48
2017	4.24	1.33	23.89
2016	3.47	1.46	29.56

7. Conclusions

The comprehensive promotion and application of e-ticket is an important project of railway passenger service in China and a core component of promoting the intelligent development of railway passenger transportation. It is not only bonded with the travel experience of tens of millions of passengers, but also signifies the construction of modern railway passenger service system. The three attributes of paper ticket, namely passenger transportation contract voucher, travel voucher and reimbursement voucher, have been effectively separated based on the studies of various key technologies of e-ticket and of the upgrade of the ticketing system architecture. The existing issues of paper tickets have been thoroughly solved, while the sense of gain and happiness of passengers during their travel has been greatly improved; the overall optimization and reconstruction of railway passenger transportation organization and passenger service process have been realized. It is a major measure to implement the strategy of "Railway Raking the Lead in Building China's Strength in Transportation" initiative advocated by CHINA RAILWAY in its 2018 Working Conference, and also a major symbol for railway enterprises to develop towards informatization and intelligence. It has far-reaching significance in the development history of railway passenger services.

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