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Public Transportation Automated Fare Collection Systems Design

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Abstract

Objectives: The article discusses the development of automated payment systems of public transport fare and accounting of passengers. The main objective of the study is a creation of the concept, which allows us to take into account the practical difficulties of collecting fare, electronic monitoring of passenger traffic and control of public transport routes. **Methods/ Statistical Analysis:** Design of the automated systems is based on analysis of business process chains and their gradual decomposition. The basis of the study approach is developed from the hypothesis about a universal technical and economic solution that allows us to integrate the autonomous elements of the system. The authors summarize the international experience in the development of similar systems in order to create the best practices. **Findings:** The study worked out the general principles of the automated fare systems in transport. The paper presents the form of deployment, describes typical solutions for the design and gives an example of its practical implementation. The authors specified a composition of business processes in the system operation at various stages. To assess the implementation prospects, the SWOT-analysis was carried out for the electronic accounting systems of the passenger traffic by using state and multiple vendors' fare cards. **Application/Improvement**: The results of the comparative study of the automated systems made it possible to complement the existing concept with internal control components for autonomous elements. The authors suggested the introduction of "stop list" units between synchronization intervals in the implementation of fare transactions, as well as differential risk transfer for the fare fixing by the system users.

Keywords: Automated Data Processing ,Control Systems, Fare, Passenger Traffic , Urban Transport

1. Introduction

In today's world, the lives of most citizens are closely linked to the use of information systems. Completeness of automation, configurability, flexibility and availability of information service and user-friendliness of various functions are the main criteria for their work. Such an information system will be applied more often and, therefore, it is convenient and advantageous to both users and owners of intellectual property. Such an information system should be customer-oriented. In addition, this system should meet the criteria of reliability and advanced requirements of the information security.

According to data provided by the IDC analysts, with forecasts of costs and cash flow trends for the development of information technologies in Russia, for 2011-2015 the average annual cost growth rate for information technologies equals 11.6%. In 2015, the annual flow of funds for the development of information technologies has reached 41.1 billion USD. In such circumstances, organizations involved in the provision of the services are advised to invest in information systems and their maintenance, as

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this leads to time reduction in the information processing in order to optimize business processes in providing the services.

The public transport enterprises are one of the promising areas in terms of the automation of data collection and processing; the accurate information on the passenger traffic is very important for them, as well as the information on revenue collection and providing travel benefits. At the same time, the urban public transport sphere has a number of unresolved issues relating to the possibility of cashless fare payment by passengers. Therefore, the development and implementation of automated systems at these enterprises is an urgent applied scientific task.

According to the European Bank for Reconstruction and Development, in the big cities of Western Europe, such as London, Berlin, Barcelona, loss of revenue collection in public transport is 2-3%, in Eastern Europe in Prague, Warsaw, Bratislava this equals 3-7%. However, these losses in Russia are up to 25% due to the use of paper tickets, the human factor and the lack of automatic account of concessionary travellers. Some papers are more or less devoted to the issue in the following fields: subsidiary financing of public transportation[1]; routing and development of optimal logistics in public transport[2]; the issue of the deployment of accounting and control system of services provided for passengers[3], and others.

2. Materials and Methods

The developments in the field of urban logistics, the state programs of public transport development and the latest publications on the organization of passenger traffic in the urban environment, as well as the modernization and improvement of the urban public transportation are the basis of the study approach[4,5,6]. The development prospects for the public transport have been presented in detail in the paper[7] The issues of formation and technological design of the automated control systems for public transport are described in the papers[8,9,10] the organization of payment systems and the establishment of flexible and rigid tariff are especially disclosed in the papers[11,12,13,14]. Solutions regarding the data integrity during the operation of automated payment and control systems in public city transport are proposed in publication[15]. A wide range of publications on the issue underscores the importance and relevance of the study.

Typological passenger traffic and payment control automation system is intended to enable the transport company to carry out transportation as efficiently as possible[16]. Given the urgent need to establish a city-wide automated fare system, the first issue that shall be solved is the issue of choice of the basic technology for the development of new payment technology. The National Payment System (NPS) technology and infrastructure are proposed to be applied as the basic technology for the phased implementation of the system in Russia after implementation of a contactless payment system on its basis. To date, the MIFARE® contactless cards are the most widely used both in Russia and abroad, the application of other types is not widely used due to technical and economic aspects of their use.

In developing the concept of automatic cashless fare system, it is necessary to form the general principles of formation, and to provide various nuances that may arise during its creation and integration. Firstly, the system should take into account both the concessionary travelers and ordinary passengers, who are not entitled to a concessionary fare. Second, the system should be constructed on the principle of "prepaid" service delivery. Third, the contactless plastic smart card protected by cryptographic means should be applied as the main instrument for accounting the right to travel. Fourth, the cost of travel should be dependent on the distance between stops.

3. Results

The Multimedia Automated Complex (MAC) is designed to provide monitoring and management of public transport, fare collection, and to control all the necessary systems of the vehicle. The MAC system is built in a modular principle and has different configurations depending on the functional requirements. The MAC is a hardware and software complex consisting of onboard devices that are installed in public transport, as well as the MAC software platform on which all solutions are built to provide GPS satellite monitoring and real-time management services[17]. The MAC software may consist of the following modules: Timetable Module; Timetable Calculation and Simulation Module; Shift Module; Fares Module; Stops Script Module; Reports Module; Fuel Control Module; Passengers Counting Module; Transport Security Module. The modules may be implemented completely independently and in any configuration.

The contactless card (a generation of Mifare® contactless smart cards) is a plastic card with a built-in microprocessor and an antenna. The operation principle is based on the information exchange between the card and a reader via radio channel. The main applications of the contactless smart cards are the fare systems of public transport, access control, etc. Each contactless card has a unique serial number. This number is specified during manufacture and cannot be changed during the lifetime of the card. The electronic card as a mean of fare payment can be applied not only in metro, buses, trams and trolley buses, but also in taxi. The Mifare® cards became widespread due to a number of advantages, such as:

- speed of payment transactions /registration processing to 0.3 seconds;
- usability, cheapness of issue in comparison with contact chip cards;
- storing the information about the account status directly on the card, which allows to pay fare without contacting the data center.

3.1 Brief Description of the Fares Module Architecture

The module provides the fare payment on public transport using the electronic ticket and the electronic social card. The options of the vehicle equipment: a conductor version (using a portable payment terminal) and a stationary terminal. The installation of the stationary payment terminals is the most effective option, which will be discussed below.

To use the module, a company is created; it is a system operator, which creates a data processing center (the DPC). Together with the operator, a card center responsible for the card production and sale is created, as well as implementation of settlements with carriers (Figure 1).

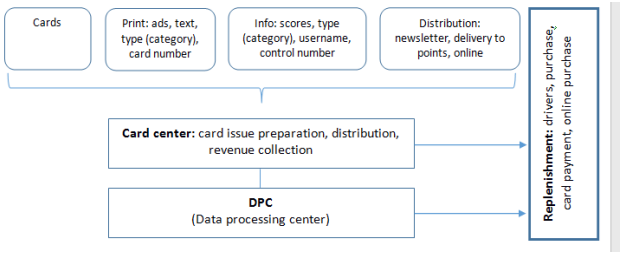

Figure 1. Fare Cards Production and Sale Process.

The public transport is equipped with the transport terminals (validators), one is on each door, which records the trip using the social and transportation cards. The transport companies (TC) set Wi-Fi points and a connection to a secure database server. On the arrival at the park, the TC loads the information on completed transactions to the database server. At the TC on the basis of the received data, reporting and analytical forms on transport activity of the company are generated and transmitted in real time to the data processing center. The Fares Module software provides data exchange between the local server databases, real-time processing of received reporting and analytical forms for the analysis of the transport companies' activity. The software is implemented in a form of separate modules having access to the common database. The functions of the Fares Module include as follows: maintenance of financial transactions database; maintenance of cards database; card conversion control; the formation of records; registration and preparation of configuration files for terminals; support and maintenance of stop-lists; interaction with other databases and data centers.

3.2 Types of Travel Documents

The multiple contactless plastic card built on the MIFARE® DESFire EV1 technology (protection CCEAL4 + chip, which corresponds to the requirements for the banking systems) should be applied as a basic non-personalized fare account instrument for urban and suburban transport. This technology will allow us to build a flexible and highly secure system of differentiated fares with an optimal ratio between security and cost of media. The card developed in accordance with this technology is virtually unlimited in lifetime and allows a virtually unlimited number of replenishments (the validity period can be up to 5 years or more, to a large extent it is determined by the physical wear and tear). The main types of cards are shown in Table 1.

Table 1. Fare Cards Classification

Types by Users	– travel card; – student; – school; – social
Types by Work Principle:	– Mifare® (all types); – smart cards; – NFC cell phone
Types by Application:	– electronic social card; – multiple renewed card; – for a certain period; – for a certain number of trips; – single-use

The concessionary travelers, as well as citizens, who will receive an electronic pensioner ID card, can use the pensioner ID card or a social insurance certificate as a travel document (for the concessionary travelers it is mandatory), which is the contactless or dual smart card. In this case, DESFire EV1 logical protocols emulation is performed on the smart card chip, and the processing technology is almost identical to the above option (it is performed in the usual way for non-concessionary replenishments).

For non-scheduled passengers (the non-concessionary ones) paper contactless travel documents designed by MIFARE® Ultralight C technology, without replenishment capabilities, should be used. The chosen technology allows achieving a minimal cost of the travel document, while maintaining a high level of the cryptographic protection. These documents will allow to effectively account a limited number of trips, and ticket price can be determined at sale at the ticket office or self-service stand.

3.3 Electronic Ticket

Electronic ticket is formed by the validator and recorded on the card; it should include the following information: the vehicle number; the route number and destination; the stop number of pick-up (fare payment); timestamp on the fare payment; trip debit cost.

"Tariff"fight against the abuse by passengers. To increase the convenience of controlling the fare payments, this system can be integrated with other automated accounting systems of the passenger traffic. In addition, in order to solve this issue on suburban transport, you may apply the following tariff system, which takes into account the following facts:

- the vast majority of passenger trips in the suburban transport is carried out between two stations;
- in 95% of cases, if the passenger arrived from point A to point B by defined transport, he would return by the same transport;
- in most cases one of these points is a station in the city or regional scale, where the ticket control can be organized at the exit from the station;
- fare controllers work on the routes, and the passengers do not know their schedule of checks.

Based on the above, the fare should be 1.5-1.8 times higher for the trip between two "new" stops than the fare for travel between the same stations in the previous ticket, but in back direction. That is, if the passenger constantly travels between two stops and pays for travel in both directions at once, the ticket price remains at the current level, and in the case of payment (or not full payment) for the current trip between these two points only in one direction, he or she will have to pay more for the following trip. The implementation of the proposed technology is possible through the use of "electronic ticket" and the selected type of the travel card chip.

Audit Fare Control. Audit fare control should be performed by controlling the electronic tickets in the passengers' travel documents (cards). To do this, handheld devices (the validators) can be applied, which allow to view all the parameters of (the last) electronic ticket stored on the card. Taking into account the preservation of the electronic ticket even after repayment of the excess amount using the compensation device, the ability to control the final trip fare is retained after a passenger exit the vehicle, i.e. it can also be carried out at the stop.

3.4 Synchronizing the System Elements

The selected system configuration and use of the electronic ticket allow to minimize the need for synchronization of the system elements. So the validators require only the initial (before running) initialization by timestamp and the vehicle and route parameters. Further, all devices can work practically in stand-alone mode. At the end of the work shift, the validators transfer the consolidated data on the received amount of fare and the repayment of excess amount for each category of passengers via the vehicle network to the Traffic Calculations Center, where the final fare figures are calculated for each category of passengers. A controller is used to connect all the validators in a single network; it performs control and data collection. The controller includes a GSM or other mobile communication module, as well as the GPS-module for determining the precise coordinates of a vehicle and time. The controller receives commands from the Control Center and sends the collected data. The entire information exchange between the elements of the system (both by wired and wireless communication channels) is performed in a protected cryptographic form[18].

3.5 Existing Automated System Description

The integrated automated fare control system on public transport in Tyumen (Russia) is an effective example of the system implementation. The fare control automation tasks on the urban transport are

solved by the Tyumen Transportation System (TTS) Company. The functions of the processing company are the following: organization of work on the implementation and use of the automated fare collection system on the urban public transport; organization of the fare system on the urban public transport (the billing); technical and server maintenance of the automated fare collection system on the urban public transport, information support; equipping the public passenger transport with terminals; travel cards issue; training of fare conductors and dispatchers of the transport companies; daily data collection on passenger traffic on routes, a number of carried passengers, including the concessionary ones, with differentiation on specific concessionary categories. The key business processes are shown in Figure 2.

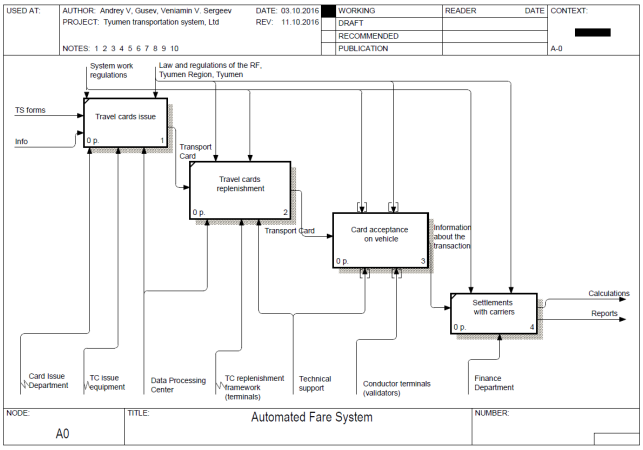

Figure 2. Key Business Processes Diagram.

Currently, the TTS issues the following kinds of the travel cards: (1) a personalized (private) travel card "Concessionary", which allows the holder to receive free or reduced fare on public transport throughout the service territory; (2) a personalized travel card "Pensioner", which allows the holder to carry out free travel on public transport in the city; (3) a personalized travel card "Schoolboy", which allows the holder to receive a discount of 80% of the fare on public transport; (4) a personalized travel card "Student", which allows the holder to receive a discount of 50% of the fare on public transport in the city; (5) a non-personalized travel card "General", which allows the holder to receive a discount on public transport.

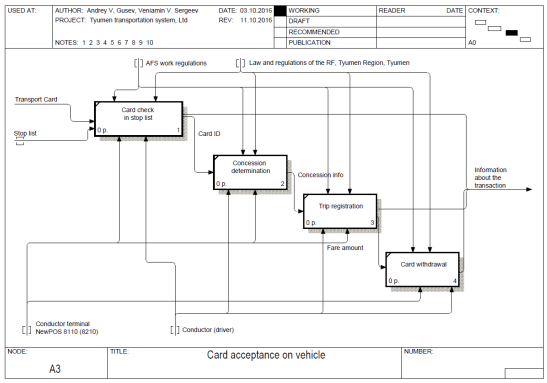

Figure 3. Fare Payment Decomposition.

In working with customers, the TTS uses a number of hardware and software instruments. To register the fact of a trip by a card user and (or) fare, bus conductors (drivers) use bus validator (POS payment terminals, such as NewPOS 8110 and NewPOS 8210 with software developed by the RLine company (http://rline.pro)). To ensure the necessary framework of replenishing cards issued by the TTS, card replenishment terminals (self-service stands) are used, which are installed at bus shelters and city offices. The replenishment terminals are a hardware and software complex consisting of a personal computer and connected peripherals (a cash acceptor, a thermal printer with a fiscal registrar, a contactless reader, etc.) and the Payment System software. The Payment System is software that enables the payment system to accept fares through the self-service terminals, websites and mobile applications. The implementation of the Fares Module is shown in Figure 3.

4. Discussion

On the basis of information supplied by the automated system, the transport company will be able to plan the transportation process, to compensate for the cost of transportation of the concessionary travelers, to improve service quality and to reduce transaction costs[19]. The measures will eventually eliminate the risks of opportunistic behavior in the forms of ex ante and ex post, while uncertainty of the business processes is limited by established scopes of control[20]. The system takes into account a variety of fares by means of transportation: tram, trolley, bus, metro, taxi, shuttle, city route (by writing off certain fares); takes into account the different fares by the routes; considers the possibility / impossibility of using this or that concession for different types of carriage in different groups of the transport companies. Analysis of the main advantages and disadvantages of the electronic fare control and collection systems in urban transport is given in Table 2.

Table 2. Electronic Passenger Traffic Accounting Systems SWOT Analysis

Advantages and Disadvantages of Electronic Accounting (Registration) Fare Cards	
Advantages	***Disadvantages***
Low cost of a card manufacture, issue and registration; Simple process of issuing cards to concessionary travelers; Information and technical infrastructure is more flexible than for the payment cards; Possibility of local processing for the needs of a certain city (or region); Easy settlement system between parties	Limited use of an accounting card; Provision complexity of the combined concessions for certain categories of passengers; Need to develop a significant amount of technical standards for the operation of the system; Need to create an appropriate framework
Advantages and Disadvantages of Electronic Accounting Fare Cards with Various Applications (Multiple Cards)	
Advantages	***Disadvantages***
Ability to select applications to be activated on cards; Universal system of contracts and payments; Ability to use a single ticket (one card) in various means of transport; Ability to personalize the card to provide a repayment in case of loss or theft of the card (the card is placed in the Stop List and blocked)	Limited use of an accounting card; Provision complexity of the combined concessions for certain categories of passengers; Need to develop a significant amount of technical standards for the operation of the system; Need to create an appropriate framework

For transport companies, the use of the contactless cards can improve service for passengers and gives the following features: a significant reduction in equipment maintenance costs; reduction of issue and conversion costs of tickets due to the longer service period of the cards; the ability to conduct a flexible tariff policy, as the introduction of new types of tickets or tariff tables is performed only by software. This makes it possible to increase the transport company's revenues at a given level of tariffs due to the optimization of the fare structure and policy; to increase revenue due to the accurate accounting of the number of trips by passengers entitled to discount or free travel; to increase revenue by eliminating counterfeit tickets based on the contactless cards.

5. Conclusion

The contactless fare collection system has great prospects for further application. However, despite the variety of theoretical and applied studies, a common approach has not been developed yet in order to apply and harmonize their use in transport. The expected effect of the system implementation implies a reduction of operating costs for the services provided, improvement of the tariff structure, the introduction of a flexible tariff system, an increase of the fare control efficiency. Such systems make it possible to establish a common procedure for accounting of the services provided to the concessionary travelers; this is a very important aspect for those authorities that implement the appropriate support of the population and contribute to their mobility in the region. The proposed solution for the design of the automated fare collection and control system for public transport gives you a clear understanding of the areas for further process optimization, where the main problem is data synchronization in stand-alone operation periods, as well as the introduction of the integrated banking product platforms.

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