Methods for implementation results assessment of the contactless fare collection system

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Abstract. The article presents the research results of the effects arising from the introduction of contactless fare collection system on public urban transport, including technical, technological, economic, organizational, managerial, environmental and synergistic effects. Based on the selected positive effects, economic benefits and possible risks associated with one or another type of effect, the results assessment method of innovative fare collection system implementation has been developed. The proposed indicators system allows making comprehensive assessment of the results of the contactless fare collection system implementation on transport by using available source data. The method application on practice will ensure a scientific and systematic approach to the innovative development of urban passenger transport.

1. Introduction

Every year due to increasing population mobility the requirements for the passenger urban transport quality are becoming more stringent, which determines the need for introduction of such innovative technologies as contactless fare collection systems (CFCS). The high speed of this technology spreading in both foreign and domestic practice necessitates the assessment of the effects obtained as an implementation result and separated projects effectiveness. Consequently, it is necessary to develop a methodological apparatus to conduct this assessment.

At the same time the effectiveness of the CFCS introduction in domestic practice is mainly attributed to savings obtaining from neglecting human labor usage reduction with other effects, which distort the final assessment value. Such approach is unacceptable when making decisions in the investment and innovation sphere of urban passenger transport. In this regard, there is a need to develop indicator’s system to assess the results of the CFCS implementation on the basis of an integrated and comprehensive approach, an important criterion of which is the calculation simplicity and initial data availability.

The following works are devoted to the problems and possibilities of using modern fare collection systems in cities all around the world [1-11]. There is neither the assessment for the current state of payment on public passenger transport, nor the attempt of qualitative evaluation of the modern technologies introduction results. Thus the author compared and identified in the research [1] the most preferred payment options for passengers using the example of the Czech Republic. It is supposed that effects will be achieved in Manila (Philippines) [2]: decreasing impact on public budget, enhanced demand management, making travel more comfortable.

It is expected that it is possible to form open and interoperable fare payment in such way that will be both convenient for customers and efficient for transit agencies in India [3]. The paper [4] presents the
report results, in which authors based on foreign approaches analysis to the implementation of modern fare payment technologies, highlighted the features and recommendations to implement them in Poland.

Based on the Chicago and London approaches [5] models of discrete card type passengers’ choice who may not have or will not want to use existing bank cards to pay for travel have been applied. The presence of some technical and technological effects due to the use of the smart toll fare collection system is mentioned in [6].

The most part of the Russian literature consists of the research related to description and analysis of various automated fare collection systems [7, 8], as well as the possibilities of their usage in a particular region [9, 10]. However, the practical calculation methods for evaluating various effects kinds are not presented.

2. Materials and methods
The following research methodology was proposed in order to achieve the goal:

- Determining the effects of the CFCS introduction for different participants groups in the transport process.
- Identifying the beneficial effects essence, economic benefits and possible risks of various effect groups from the CFCS introduction on urban passenger transport.
- Determining technics to evaluate selected effect groups.
- Forming a scorecard to assess the effects from the CFCS implementation.
- Developing methods for integrated results assessment of the CFCS implementation on urban passenger transport.

There have been used the following methods: grouping method, index and comparative analysis methods.

3. Results and discussion

3.1. Study of the CFCS introduction effects on urban passenger transport
The spread of CFCS technology on urban passenger transport for the Russian reality is dynamic, since it offers a lot of effects for all participants in the transport process, which will be considered further.

So for transport operators the effect is expressed as an increase of the tolls collection; accelerating the turnover of funds; management and control automation of passenger traffic on the route; modern image of transport formation in cities; urban passenger transport integration; cost reduction and profit growth due to an increase in passenger traffic, etc.

Passengers receive a fast, safe and convenient way to pay; expanding the possibilities of using various maps types for all urban passenger transport types; comfortable and stress-free payment conditions; automatic funds conversion for foreign tourists; automatic selection of favorable tariff, etc.

CFCS provides the preservation of existing work logic and transport card infrastructure to the carriers; increasing the control points capacity; a significant cost reduction for issuing transport cards and maintaining the “ticket-and-cash” infrastructure; transparency in business and reporting; improving the operational planning quality and resource allocation, etc.

Significant for each CFCS participant effects have strict certainty by type, which is important for assessment, predicting the consequences and enhancing the effect with managerial influences help. Therefore, this issue should be considered in terms of the occurrence of a beneficial effect, economy and risks arising from a separated effect type.

The technical effect is expressed in improving the beneficial vehicles use, transport infrastructure, transport system as a whole since new CFCS technology platform introduction requires the reconstruction, modernization or equipment replacement.

The beneficial effect in this case is determined by the volume of decommissioning equipment for fare payment by traditional methods, the quantitative parameters of the infrastructure being created for the CFCS introduction, vehicles equipped with the CFCS, the software and the platforms integration of
the CFCS participants to ensure data exchange, the technical platform formation for creating integrated databases.

In this regard, it is expected that savings are received by expenses reducing for maintaining the ticket-cash fare payment technology and its infrastructure, for replicating tickets, tokens, coins, cards, as well as expenses reducing for human labor involved into tickets sale and other traditional carriers for fare payment.

At the same time, there may be risks associated with technical failures and halting in the CFCS work being introduced, with the lack of sufficient technical resources, risks of usual processes disintegration.

The technological effect is revealed through the need of improvement, replacement or development and new technology use that significantly improves the quality of the payment process, both for operators and passengers.

The beneficial effect is expressed in the payment operations speed, safety and personal and corporate data security, the availability of the CFCS process standard, time reduction for one payment transaction, and an increase in vehicle capacity.

The economic component consists of an increase in the payment for travel collection, transparency of financial flows, resources reduction for CFCS maintenance, time losses reduction for the population when paying for travel, expenses reduction for maintaining of outdated payment technologies.

The technological effect is accompanied by such risks as the failures risk during the retuning of the technological process between the CFCS participants and the incompatibility risk of the technological and peripheral equipment.

The organizational and managerial effect is determined by a clear roles and functions definition of each element in the transport system, rhythm, line operation accuracy, organizing the big data streams collection, obtaining operational information about all payment transactions on all types of urban transport, traffic and financial flows legalization.

Consequently, the beneficial effect can be determined by growth assessment of the CFCS participant’s actions organization and its coordination, automation and management intensification level, the efficiency degree in obtaining data on the passenger traffic volume, the number of transactions, trips and benefits usage.

Obtained economic benefits in this case are calculated based on increasing profits from transportation due to fare payments collection growth and automated fare payments monitoring, the growth in the carriers and transport operators expenses coverage, the accuracy of compensation payments from different budgets’ levels to cover benefits.

At the same time, the controllability loss risk due to highly automated processes, the failures risk due to the complexity of the managed system, the increase of CFCS participants’ and other transport service market participants’ competition are not excluded.

The economic effect is estimated in monetary terms and in this context it is always crucial. This can be explained by the expediency or inexpediency of the introduction and wide dissemination of any innovation, technology or product, which CFCS is.

In a general sense, the economic effect consists of increasing income and profits amount, as well as expenses reducing for maintaining the traditional fare payment infrastructure, which means:

- reduction of carriers production costs for CFCS technology;
- reduction the diversity maintaining cost of CFCS carriers;
- reduction of human labor costs;
- reduction of the travel cost by reducing maintaining expenses on outdated fare payment infrastructure.

The risks connected with CFCS implementation are associated, first of all, with the commercial benefits loss as a result of the participants’ refusal to support the CFCS technology and passenger traffic reduction.

The social effect is characterized by society satisfaction with the social needs and the services provided quality.

The beneficial effect is expressed through the city’s transport system renewal, the convenience of
urban passenger transport usage, the population reorientation towards the urban passenger transport usage, the simplicity and accessibility of usage for all city’s population categories, working conditions improvement in transport and, as a result, population quality of life improvement as a whole.

However, there is also a negative side in terms of the social component, which is to reduce the number of jobs. This reduction is aggravated by the innovation resistance risk and political decision-making risk.

The environmental effects for CFCS implementation are associated with equipment dismantling of the traditional fare collection system and new equipment supply, reducing emissions and waste.

The beneficial effect is expressed in environmental efficiency improvement, in processes’ virtualization and the fare payment material base reduction, resource and energy saving.

However, there is a risk of return to traditional technologies.

The synergistic effect seems to be the most important effect for CFCS introduction evaluation but at the same time its evaluation method is the most difficult since the effects can be assessed before system implemented commissioning is completed only on the experts’ survey bases who predict implementation effectiveness.

The synergistic effect means the result existence of a peculiar increase in innovations, the requirement of which is caused by CFCS introduction in technological processes of organizing transportation by urban passenger transport, for both individual carriers and the transport system as a whole.

In addition, synergistic effect involves taking into consideration the aggregated values of cost reduction, increase in profitability and growth in transport operations profitability.

Accordingly, in this case it is necessary to take into account the presence of innovation implementation complex risks, including the non-acceptance risks from passenger transport market participants and political risks.

Thus, the foreign and domestic experience study made it possible to identify the expected effects, cost savings and CFCS introduction risks, on the basis of which the method for this technology implementation results assessment has been developed.

3.2. Method for assessment CFCS implementation results on urban passenger transport

The developed method involves comprehensive indicator calculation for assessment each type of effects. To assess the technical, technological, economic and social effects, it is proposed to define an integral indicator in the range from 0 to 1 as a weighted sum of the component indicators:

\[
E = \frac{\sum_{i=1}^{n} E_i \cdot w_i}{100 \sum_{i=1}^{n} w_i},
\]

where \(E_i\) – the component indicator value in the integral indicator of the effect assessment; \(w_i\) – the component indicator significance (weight) in the integral indicator of the effect assessment (determined by expert); \(n\) – the number of integral indicator components.

Evaluation of the organizational and managerial, environmental and synergistic effects is determined in other technics.

The integral indicator for technical effect assessment of CFCS introduction \((T_i)\) is based on the following indicators calculation with corresponding significance (weights):

- costs reduction indicator on maintaining the ticket-cash technology and the corresponding infrastructure (10);
- costs reduction indicator on replicating tickets, tokens, coins, cards (5);
- costs reduction indicator on human labor involved in the process of selling tickets and other traditional carriers to pay for travel (9);
- system technical reliability indicator (8);
- vehicle equipment ratio with CFCS technology at enterprise level (8);
- vehicle equipment ratio with CFCS technology at city level (10).
The costs reduction indicator on maintaining the ticket-cash technology and the corresponding infrastructure \( T_{tc} \) is determined by the formula:

\[
T_{tc} = \left( 1 - \frac{C_{tc1}}{I_p \cdot C_{tc0}} \right) \cdot 100 ,
\]

(2)

where \( I_p \) – price increase index in the reporting year (after CFCS implementation) relative to the base year; \( C_{tc1} \) – planned costs on maintaining the ticket-cash technology and the corresponding infrastructure after CFCS implementation; \( C_{tc0} \) – actual costs on maintaining the ticket-cash technology and the corresponding infrastructure before CFCS implementation.

The costs reduction indicator on replicating tickets, tokens, coins, cards \( T_r \) is determined by the formula:

\[
T_r = \left( 1 - \frac{C_{r1}}{I_p \cdot C_{r0}} \right) \cdot 100 ,
\]

(3)

where \( C_{r1} \) – planned costs on replicating tickets, tokens, coins, cards after CFCS implementation; \( C_{r0} \) – actual costs on replicating tickets, tokens, coins, cards before CFCS implementation.

The costs reduction indicator on human labor involved in the process of selling tickets and other traditional carriers to pay for travel \( T_i \) is determined by the formula:

\[
T_i = \left( 1 - \frac{C_{i1}}{I_p \cdot C_{i0}} \right) \cdot 100 ,
\]

(4)

where \( C_{i1} \) – planned costs on human labor involved in the process of selling tickets and other traditional carriers to pay for travel after CFCS implementation; \( C_{i0} \) – actual costs on human labor before CFCS implementation.

The system technical reliability indicator \( T_f \) characterizes the failure-free operation system probability and is related to the distribution function of the trouble-free operation time by the following relation:

\[
T_f = 1 - Q_t ,
\]

(5)

where \( Q_t \) – distribution function of CFCS no-failure time which is the probability of a failure during the time \( t \).

It is obvious that \( 0 \leq T_f \leq 1 \).

The vehicle equipment ratio with CFCS technology at enterprise level \( T_{eq/ent} \) is defined as follows:

\[
T_{eq/ent} = \left( \frac{N_{eq}}{N_{\Sigma}} \right) \cdot 100 ,
\]

(6)

where \( N_{eq} \) – the number of vehicles equipped with CFCS; \( N_{\Sigma} \) – average number of vehicles in the enterprise fleet.

Desired coefficient value – 1, which means equipping the entire vehicles fleet.

The vehicle equipment ratio with CFCS technology on enterprise level \( T_{eq/c} \) is defined and calculated similarly to the equipment ratio at the enterprise level (formula 6).

The integral indicator for the technological effect assessment of CFCS introduction (TL) includes six indicators with corresponding weights of importance:

- fare payment speed growth rate (6);
- data security indicator (10);
- vehicle passenger capacity growth rate (9);
- fare collection growth rate (10);
- indicator of costs reduction for CFCS maintaining (8);
- indicator of costs reduction for outdated fare collection technologies maintaining (7).
The fare payment speed growth rate indicates how much faster the fare payment has become for a passenger calculated in percentage:

\[ TL_{sp} = \left( \frac{t_1 - t_0}{t_0} \right) \times 100 \], \tag{7} 

where \( t_1 \) – time required for the passenger to pay fare after CFCS introduction, ms; \( t_0 \) – time required for the passenger to pay fare before CFCS introduction, ms.

The data security indicator shows the completed transactions percentage in value terms made without financial flows loss and is calculated by the formula:

\[ TL_s = \left( \frac{N_x}{N_{xy}} \right) \times 100 \], \tag{8} 

where \( N_x \) – the number of transactions in value terms made without financial flows loss; \( N_{xy} \) – total number of transactions in value terms performed in the reporting period.

The vehicle passenger capacity growth rate characterizes the possible passenger transportation volume by a motor vehicle. It depends on bus passenger capacity, the passenger capacity utilization rate, the idle time at stops, and hence the average operating speed. It is calculated by the following formula:

\[ TL_{pc} = \left( \frac{Q_1}{Q_0} \right) \times 100 \], \tag{9} 

where \( Q_1 \) – possible passenger traffic volume after CFCS implementation, pass.; \( Q_0 \) – actual passenger traffic volume before CFCS implementation, pass.

The fare collection growth rate is calculated by the following formula:

\[ TL_f = \left( \frac{F_1}{F_0} \right) \times 100 \], \tag{10} 

where \( F_1 \) – transactions amount in value terms after CFCS introduction; \( F_0 \) – transactions amount in value terms before CFCS introduction.

The indicator of costs reduction for CFCS maintaining is determined by the formula:

\[ TL_{\text{CFCS}} = \left( 1 - \frac{C_{\text{CFCS}1}}{I_p \cdot C_{\text{CFCS}0}} \right) \times 100 \], \tag{11} 

where \( C_{\text{CFCS}1} \) – planned costs for CFCS performance maintaining after the innovation introduction; \( C_{\text{CFCS}0} \) – actual costs for performance maintaining of the prior fare collection system before innovation introduction.

The indicator of costs reduction for outdated fare collection technologies maintaining is determined by the formula:

\[ TL_{os} = \left( 1 - \frac{C_{\text{os}1}}{I_p \cdot C_{\text{os}0}} \right) \times 100 \], \tag{12} 

where \( C_{\text{os}1} \) – planned costs for maintaining the outdated fare payment technology operability used after innovation introduction; \( C_{\text{os}0} \) – actual costs for maintaining the outdated fare payment technology operability used before innovation introduction.

As indicators of comprehensive economic effect assessment of CFCS introduction (\( E \)) with the corresponding weights, it is proposed to use the following ones:

- net present value (8);
- profitability index (9);
- return on investment (9);
- internal rate of return (7);
- revenue growth rate (10);
indicator of savings on the outdated infrastructure for fare payment maintenance (5);  
indicator of costs reduction for carrier production (7).

Net present value (NPV) [11]:

$$\text{NPV} = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \ldots + \frac{CF_n}{(1+r)^n} - IC,$$

where \(CF_i\) – cash flow obtained during period \(i\); \(r\) – discount rate (or interest rate); \(IC\) – initial capital; \(n\) – period number.

Profitability index (PI) is NPV technic modification and also uses information about discounted cash flows:

$$\text{PI} = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i} / IC.$$

Return on investment (ROI) is a generalized formula for analyzing the arbitrary investments in assets profitability:

$$\text{ROI} = \frac{\text{Net Benefits}}{\text{Costs}} \cdot 100.$$

Internal rate of return (IRR) is based on the discounted cash flow method. In essence, this is the discount rate of the free cash flow generated by the project which balances the project net present value and the initial investment amount in this project. In the calculations IRR is the discount rate at which the net present value equals zero:

$$\sum_{i=1}^{n} \frac{CF_i}{(1+IRR)^i} - IC = 0.$$

The revenue growth rate is calculated by the formula:

$$E_{rev} = \left( \frac{R_1}{R_0} \right) \cdot 100,$$

where \(E_1\) – revenue from transportation after CFCS introduction; \(E_0\) – revenue from transportation before CFCS introduction.

The indicator of savings on the outdated infrastructure for fare payment maintenance including the cost of maintaining carriers’ variety for fare payment:

$$E_{inf \_r} = \left( 1 - \frac{C_{inf \_r 1}}{C_{inf \_r 0}} \right) \cdot 100,$$

where \(C_{inf \_r 1}\) – costs of outdated fare payment infrastructure maintaining taking into account the cost of maintaining carriers’ variety for fare payment after CFCS introduction; \(C_{inf \_r 0}\) – costs of outdated fare payment infrastructure maintaining taking into account the cost of maintaining carriers’ variety for fare payment before CFCS introduction.

The indicator of costs reduction for carrier production is calculated by the formula:

$$E_c = \left( 1 - \frac{C_{c1}}{C_{c0}} \right) \cdot 100,$$

where \(C_{c1}\) – carriers’ production costs for fare payment after CFCS introduction; \(C_{c0}\) – carriers’ production costs for fare payment before CFCS introduction.

The social effect calculation of CFCS introduction (S) is proposed to be carried out through an integral indicator which takes into account the passengers movement service level by the following indicators with the corresponding weights:

- comfort index of paying for a trip in a vehicle (10);
- comfort index of embarking (disembarking) passengers in (out) a vehicle (8);
- comfort index of passengers’ trip (trip attractiveness) (9).
The comfort index of paying for a trip in a vehicle depends on the availability of modern fare payment system in a vehicle:

\[ S_{\text{conf}} = \frac{N_{\text{conf}}}{N_S}, \quad (20) \]

where \( N_{\text{conf}} \) – the number of vehicles that meet the requirements; \( N_S \) – total number of vehicles on the route network.

The value of the indicator should strive to 1.

The comfort index of embarking (disembarking) passengers in (out of) a vehicle is characterized by a reduction in vehicle idle time at the stop for passengers’ embarkation-disembarkation:

\[ S_{\text{idle}} = \frac{t_{\text{idle,1}}}{t_{\text{idle,0}}}, \quad (21) \]

where \( t_{\text{idle,1}} \) – the vehicle idle time at the stop for passengers’ embarkation-disembarkation after CFCS introduction, min; \( t_{\text{idle,0}} \) – the vehicle idle time at the stop for passengers’ embarkation-disembarkation before CFCS introduction, min.

The comfort index of passengers’ travel attractiveness on public transport is provided by the use of rolling stock that meets the passengers’ needs and requirements for transportation and is characterized by an increase in the number of passengers who use urban passenger transport instead of a personal car:

\[ S_{\text{attr}} = \frac{Q_{\text{pass,1}}}{Q_{\text{pass,0}}}, \quad (22) \]

where \( Q_{\text{pass,1}} \) – the actual volume of passenger traffic after CFCS implementation during the reporting period; \( Q_{\text{pass,0}} \) – the actual volume of passenger traffic before CFCS implementation.

The environmental effect (En) is estimated by using an indicator characterizing the harmful emissions reduction, waste and debris as a CFCS implementation result and is estimated by the formula:

\[ En = \left( 1 - \frac{Q_{\text{em,1}}}{Q_{\text{em,0}}} \right), \quad (23) \]

where \( Q_{\text{em,1}} \) – the planned amount of harmful emissions, waste and debris as a CFCS implementation result; \( Q_{\text{em,0}} \) – the actual amount of harmful emissions, waste and garbage before CFCS introduction.

In the field of urban passenger’s transport, the organizational and managerial effect OM of CFCS introduction is understood as the benefits that a passenger will receive as innovation result and, therefore, is determined through the transport services quality for passengers:

\[ OM = K_1 \cdot K_2 \cdot K_3 \cdot K_4, \quad (24) \]

where \( K_1 \) – coefficient of relative time spent on the passengers’ movement; \( K_2 \) – coefficient of the relative bus cabin filling; \( K_3 \) – coefficient of bus traffic regularity; \( K_4 \) – coefficient of accidents level dynamic measurement. The assessment of transport services quality for passengers is carried out according to the limit or scale standards.

The coefficient of relative time spent on the passengers’ movement is calculated by the formula:

\[ K_1 = \frac{t_{\text{conf}}}{t_{\text{fact}}}, \quad (25) \]

where \( t_{\text{fact}} \) – time spent on a trip in actual (real) conditions, min.; \( t_{\text{conf}} \) – time spent on travel in “theoretically absolutely comfortable conditions”, min.

The coefficient of the relative bus cabin filling is estimated by the formula:

\[ K_2 = \frac{\gamma_{\text{st}}}{\gamma_{\text{fact}}}, \quad (26) \]

where \( \gamma_{\text{st}} \) – standard value of bus cabin filling, in rush hours \( \gamma_{\text{st}} = 0.70 / 0.78 \), during the day \( \gamma_{\text{st}} = 0.28 \), it is advisable to take an average value \( \gamma_{\text{st}} = 0.50 / 0.65 \) (depending on the buses model and providing that all seats must be occupied); \( \gamma_{\text{fact}} \) – the actual filling ratio.
The coefficient of bus traffic regularity is determined:

$$K_3 = \frac{N_{t}^{\text{fact}}}{N_{t}^{\text{sch}}}$$

(27)

where $N_{t}^{\text{fact}}$ – the number of actually performed trips; $N_{t}^{\text{sch}}$ – number of scheduled trips.

The indicators group for CFCS introduction synergistic effect assessment includes:

- indicator of transport company competitiveness;
- growth rate of transport profitability;
- indicator of transport services attractiveness on urban passenger transport for residents and visitors.

The indicator of transport company competitiveness and indicator of transport services attractiveness on urban passenger transport for residents and visitors are represented as qualitative indicators and can be evaluated by experts. The growth rate of transport profitability characterizes the increase in the economic activity efficiency of city transport enterprises.

To determine the cumulative effect of CFCS introduction (SE) the proposed integral indicators for evaluating 6 types of effects (without taking into account the synergistic effect) must be summarized:

$$SE = T + TL + OM + E + S + En \rightarrow 8.$$  

(29)

The possible cumulative effect is 8. Approximation of the innovation introduction cumulative effect to 8 indicates the feasibility of its implementation.

The developed indicators system makes it possible to evaluate various types of selected effects, which seems to be complete and complex. At the same time, in practice, in the assessing results process of the CFCS implementation in a particular region any of the selected indicators groups may be supplemented with another indicator or, conversely, reduced depending on the priority tasks of the specific study.

4. Conclusion

The proposed indicators system is intended for using as road transport enterprises and transport operators in the cities of the Russian Federation, involving CFCS introduction on urban passenger transport.

The official statistics of the Federal State Statistics Service, departmental statistics and statistics collected by state committees and enterprises were used as baseline data for CFCS effectiveness assessment. This indicates the baseline data availability and simplicity of application of developed method.

The use of comprehensive, scientifically based approach for innovative technologies implementation results assessment on transport allows to obtain the data about necessary adjustments for the project being implemented and directions for further innovative technologies improvement in order to eliminate shortcomings and maximize the beneficial effects.

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