



ENHANCING THE OPERATIONAL EFFICIENCY OF PUBLIC TRANSPORT THROUGH AUTOMATED FARE COLLECTION SYSTEMS

Nguyen Thi Bich Hang

University of Transport and Communications, No 3 Cau Giay Street, Hanoi, Vietnam

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* *Corresponding author*

Email: hangntb@utc.edu.vn; Tel: 0903039092

Abstract. Public transport systems in major urban areas of Vietnam have experienced significant growth in recent years, however, the application of information technology in their management and operation remains limited. In cities such as Hanoi and Ho Chi Minh City, fare collection on bus networks is still predominantly conducted manually, with ticket counting and data recording also performed using traditional methods. This approach not only leads to high labor costs but also reduces efficiency in data management and service planning. These limitations hinder the implementation of advanced operational and policy mechanisms, including integrated fare systems, direct passenger-based subsidy schemes, and data-driven service planning that can adapt to fluctuations in travel demand. This study examines the technical, technological, and socio-economic prerequisites for implementing automated fare collection (AFC) systems in Vietnam. Based on this analysis, it proposes a set of solutions aimed at enhancing the operational efficiency and overall performance of urban public transport through the automation and digitalization of fare collection processes.

Keywords: public transport, automated fare collection (AFC), integrated fare policy, passenger subsidies, ridership growth, operational efficiency.

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1. INTRODUCTION

Despite the growing interest in Automated Fare Collection (AFC) systems and their recognized benefits in improving operational efficiency and service quality, existing studies

have primarily focused on technical design, payment technologies, and implementation experiences in developed countries. Limited attention has been paid to the challenges of deploying AFC systems in developing contexts, particularly in Southeast Asia [1-6].

In Vietnam, current AFC applications remain fragmented and underdeveloped, with a lack of system interoperability and integration across different modes of public transport. More importantly, while AFC systems are capable of generating large volumes of passenger data, there is a significant gap in the effective processing and utilization of these data for management and decision-making purposes. Existing practices largely emphasize fare collection functions, rather than leveraging data-driven approaches to optimize operations and support policy formulation. Therefore, there is a need for comprehensive research that not only examines the requirements and conditions for AFC implementation but also explores how passenger data can be systematically processed and utilized to enhance operational efficiency and management effectiveness in public transport system [7-13].

This study aims to examine the role of AFC systems as a critical data infrastructure for improving the operational efficiency of public passenger transport in major urban areas in Vietnam. Specifically, the study pursues three main objectives. First, it clarifies the distinction between AFC systems and cashless payment systems, with a particular focus on their differences in passenger data acquisition, data processing, and fare revenue management mechanisms. Second, it evaluates the current status of AFC system development and operation in Ha Noi and Ho Chi Minh city, highlighting key technical, institutional, and operational challenges. Third, based on the analysis of AFC-generated data, the study proposes a set of solutions to enhance the operational efficiency of public transport systems, particularly in terms of service planning, fare policy design, and performance-based subsidy allocation.

The findings are expected to contribute to the ongoing transition from fragmented, mode-specific ticketing systems toward integrated, data-driven public transport management frameworks in developing urban contexts.

2. AUTOMATED FARE COLLECTION SYSTEMS AND DATA UTILIZATION FOR MANAGEMENT

2.1. Overview of Automated Fare Collection Systems

In public passenger transport systems, fare collection mechanisms have evolved through several stages, ranging from manual to fully automated approaches [1-3].

The most basic form is manual fare collection, which relies on paper tickets and on-board staff who are responsible for selling and inspecting tickets. In this system, revenue is recorded manually and submitted to the operating company at the end of each working day, resulting in high labor costs and limited operational efficiency. To address these limitations, semi-automated fare collection systems were introduced. These systems typically use paper tickets or coin-operated ticketing machines installed on vehicles, allowing passengers to purchase and print tickets independently. Although this approach reduces the need for on-board staff, it requires a high level of passenger compliance and cooperation. Moreover, revenue collection and reporting processes still depend largely on manual handling.

With advancements in information technology, AFC systems have emerged as a more efficient alternative. AFC systems utilize electronic devices and digital technologies to automate fare payment and revenue management, thereby significantly reducing human

intervention. Depending on the level of technological development, different types of fare media can be employed.

- Early AFC systems made use of magnetic cards, which were introduced in the 1970s. These cards store fixed information on a magnetic stripe; however, their limited security, durability, and storage capacity have led to their gradual obsolescence.

- Subsequently, smart card technologies, including both contact and contactless cards, were developed in the 1990s. These systems employ Radio Frequency Identification (RFID) or Near Field Communication (NFC) technologies to enable secure and efficient data exchange between the card—equipped with an embedded microchip—and the reader device.

- More recently, the development of mobile technologies has enabled the adoption of mobile-based fare media. Passengers can use smartphones as virtual smart cards if equipped with NFC or RFID capabilities. In addition, mobile payment platforms such as ZaloPay, MoMo, and QR code-based systems provide flexible and convenient alternatives for fare payment.

An AFC system is typically structured into multiple hierarchical levels, each responsible for specific functions within the overall operation [4-6] (Figure 1).

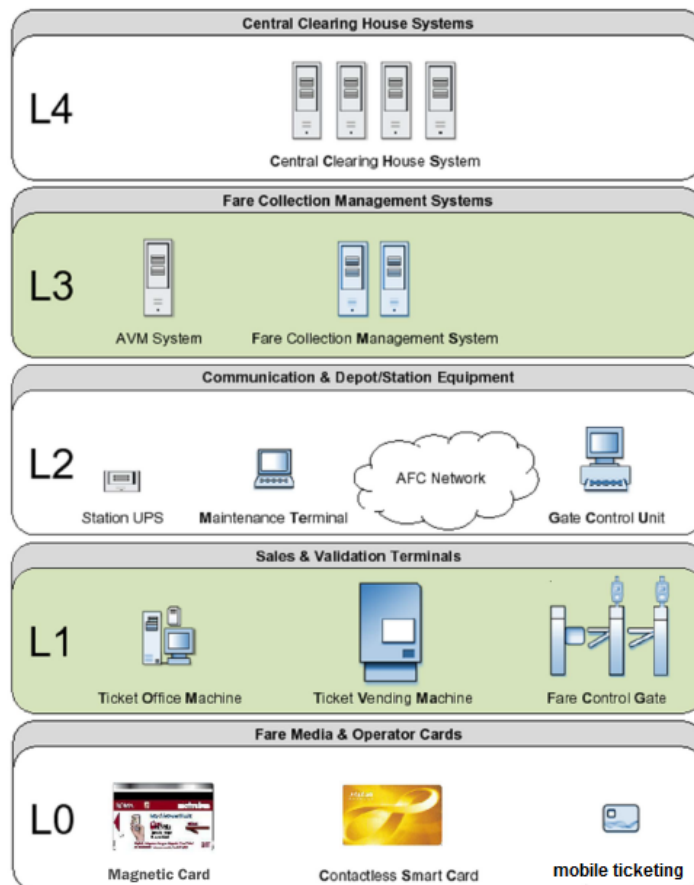


Figure 1. AFC Reference Model [4].

- **Level 0 – Fare Media:** This level consists of payment instruments used by passengers, including magnetic cards, smart cards, and mobile-based fare media. These media serve as the primary interface between users and the AFC system. In addition, emerging identity-based access mechanisms, such as biometric characteristics of users (e.g., facial recognition,

fingerprint), may also be incorporated as complementary authentication factors in advanced AFC systems (Figure 2).



Figure 2. Fare media in public transport [5].

• **Level 1 – Front-End Devices:** This level includes card reading and writing devices such as ticket vending machines (installed on streets, vehicles, or at stations), ticket office machines, and fare control gates. These devices enable fare transactions and initial data capture. In addition, advanced AFC systems may incorporate AI-enabled facial recognition cameras and fingerprint scanning devices at fare gates to support identity-based authentication and access control (Figure 3).



Figure 3. Devices to Read/Write Fare Media [6].

• **Level 2 – Depot/Station Equipment:** At this level, devices installed at depots or terminals are responsible for aggregating and transmitting operational data through telecommunications networks to the central system.

• **Level 3 – Back-Office System:** This level comprises servers and management software used for processing and managing collected data. Key functions include:

- Fare management: changing of fares and fare products
- Media management: support for blacklisting of lost/stolen media

- Reporting: generation of periodic operational reports, financial statements, and passenger travel records

• **Level 4 – Central Clearing House (CCH):** This level facilitates data exchange and financial settlement among multiple stakeholders. In integrated transport environments involving multiple operators and interoperable systems, a Central Clearing House Solution (CCHS) is essential for managing financial transactions and related services. Its primary function is to allocate revenue and perform settlement among participating entities - such as transport operators and ticketing agents - based on predefined agreements. Clearing revenues are typically settled periodically through the banking system.

In addition, interoperability of fare media and payment methods is a critical requirement in AFC systems. It enables passengers to use a single card across multiple transport modes and potentially integrate with banking and credit card systems, thereby enhancing user convenience [7]. To ensure interoperability, it is recommended to adopt available standards and open specifications (including security, data models, and data exchange protocols), while avoiding proprietary and incompatible systems. Furthermore, coordinated investment in equipment, technology, and infrastructure across all public transport modes is necessary to achieve a fully integrated AFC system.

2.2. Data Collection and Processing in AFC Systems

The data collection and processing workflow of an AFC system can be outlined in Figure 4 as follows [8]:

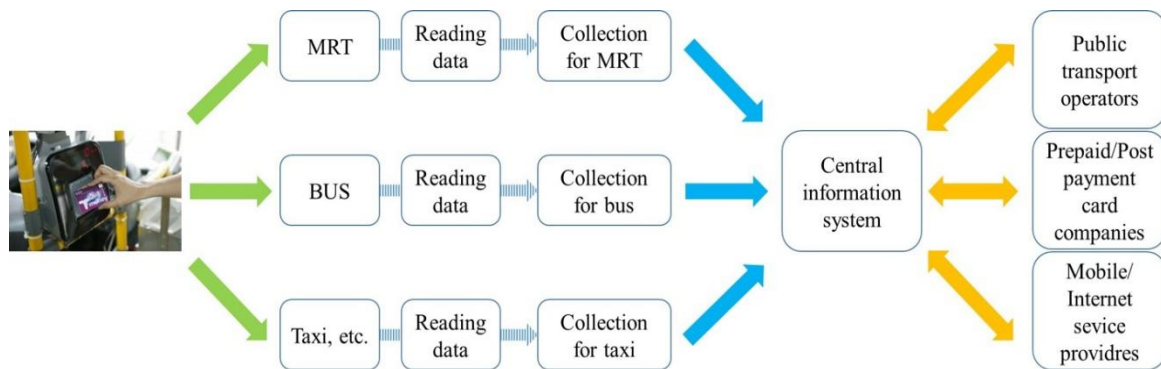


Figure 4. Data collection and processing in AFC system.

Step 1 – User Identification : This step involves the recognition of fare media by card readers. When a passenger presents a card near a reader installed on buses, taxis, or at metro stations, the user’s information is captured and transmitted to the device.

Step 2 – Data Acquisition : This stage focuses on collecting information related to ticket usage and passenger trips. Data captured by card readers across different transport modes are transmitted to the data collection system.

Step 3 – Data Transmission and Clearing : The collected data are forwarded to a centralized payment and clearing system for further processing and integration.

Step 4 – Data Utilization and Revenue Allocation : At this stage, transport operators and related stakeholders utilize the data. Based on predefined agreements, revenues are

allocated among transport operators, financial institutions, mobile service providers, and other relevant entities.

Step 5 – Validation and System Coordination : Relevant organizations provide the clearing center with updated information on valid and invalid fare media, ensuring the smooth and secure operation of the AFC system

Beyond fare collection and revenue distribution, AFC data can be further exploited to support transport system operations and management. Key categories of data include:

- **Operational data:** Information related to vehicle operations, such as passenger boarding and alighting counts at each stop, passenger load per segment, vehicle arrival and departure times, transfer frequency, transport modes used within a journey, and passenger flow along route segments.
- **Passenger travel data:** Information describing travel behavior, including transport modes used, average travel time, average travel cost, average trip distance, entry and exit times within the public transport system, and average transfer times between modes.
- **Fare media data:** Information related to ticketing instruments, including card serial numbers, card types, fare calculation rules, and passenger categories associated with each card.

A critical requirement for maximizing the value of AFC systems is the integration of these data into a centralized data warehouse, where they are stored in standardized formats (e.g., binary or structured data formats). Fragmented data storage across different operators significantly limits the ability to analyze and utilize data effectively in the future. Therefore, a unified data management approach is essential for enabling data-driven decision-making and improving overall system performance.

3. CURRENT STATUS AND APPLICATION POTENTIAL OF AUTOMATED FARE COLLECTION IN PUBLIC TRANSPORT IN VIETNAM

Public passenger transport in Vietnam is currently dominated by bus services. Nationwide, only three urban rail lines have been put into operation, including two lines in Hanoi and one line in Ho Chi Minh City. AFC systems have also primarily been developed and implemented in these two cities.

In Hanoi, fare collection on urban rail lines has been automated through AFC systems installed at stations. The AFC systems of the Nhon – Hanoi Station line and the Cat Linh – Ha Dong line operate reliably, ensuring accurate data processing with minimal errors. By February 2026, Hanoi had implemented a unified electronic ticket validation system across Metro Line 2A and Line 3, enabling passengers to use a common set of fare media, including QR codes, national ID cards, and bank cards, across both lines. However, the extent of backend integration, including revenue clearing and fare policy coordination, remains less clearly documented. For the bus network, since late November 2023, an electronic ticketing system has been piloted on 25 bus routes. In addition to physical smart cards, from April 2024, the “Hanoi Transport Ticket Card” mobile application has been introduced, utilizing dynamic QR code-based virtual tickets for monthly passes and free-ticket categories, thereby enhancing passenger convenience and reducing card issuance costs.

A key challenge for Hanoi is to achieve interoperability between AFC systems across urban rail lines and the bus network. To address this, the Hanoi People's Committee has approved the implementation of an integrated multimodal e-ticketing system under an IT service leasing model. This includes on-board ticketing devices, handheld validators, centralized servers, and management software. The service period is planned from 2025 to 2030, with full deployment across the bus network in 2025, followed by integration with urban rail lines and other services such as road tolling and parking fees in 2026. Upon completion, all equipment, data, and software usage rights will be transferred to the city [9].

In Ho Chi Minh City, Metro Line 1 (Ben Thanh – Suoi Tien) began operations in January 2025, while the AFC system using smart IC cards was only introduced in July 2025. Prior to this, passengers relied on manual ticketing, bank cards, e-wallets, and mobile tickets via the HCMC Metro app. Current ticket machines accept only cash and do not allow refunds, creating inconvenience; therefore, multiple payment methods are still operated in parallel. For bus services, electronic ticketing has been piloted since 2019 and expanded to a large portion of the network. However, cash payments remain dominant, requiring onboard staff for fare collection [10].

The city has established technical standards for integrated ticketing and proposed AFC service deployment, though implementation remains limited. The introduction of the MultiPass card marks progress toward unified payment; however, it mainly supports cashless transactions and does not yet enable effective data collection for management. The implementation of AFC systems in Vietnam reflects a combination of progress and ongoing challenges. While initial deployments demonstrate the technical feasibility of AFC, system development remains fragmented, particularly in terms of interoperability across transport modes and operators. This limits both user convenience and the potential for integrated and seamless public transport services.

A critical issue lies in the absence of a unified data framework. Although AFC systems generate substantial volumes of data, the lack of integration and centralized management restricts their effective use for system-wide analysis and decision-making. Consequently, the application of data-driven approaches in transport planning and operations remains limited.

From an institutional perspective, current implementation models offer practical advantages in terms of investment and deployment. However, they also introduce challenges related to data governance, standardization, and long-term system integration. Overall, the development of an effective AFC ecosystem requires not only technological advancement but also coordinated efforts in data standardization, system integration, and governance. Addressing these aspects is essential to fully realize the benefits of AFC systems in improving operational efficiency and supporting sustainable public transport development.

4. ENHANCING PUBLIC TRANSPORT EFFICIENCY THROUGH THE APPLICATION OF AUTOMATED FARE COLLECTION SYSTEMS

The findings highlight that AFC systems should be viewed not merely as fare payment tools but as critical data infrastructures for modern public transport management. While AFC implementation improves passenger convenience through cashless and multimodal ticketing, its most significant value lies in enabling data-driven decision-making and performance-based management. This study focuses on solutions that utilize data collected and generated by AFC

systems to improve the operational efficiency of public passenger transport in major cities in Vietnam.

4.1. Subsidy Allocation Based on Passenger Volume

Public passenger transport is characterized by significant temporal and spatial variations in passenger demand, relatively short average trip distances compared to route length, and low operational speeds due to frequent stops and operation under dense and complex traffic conditions. As a result, operating costs are relatively high, while fare revenues are often insufficient to cover these costs. To encourage public transport usage through affordable fares (typically lower than the actual cost of service provision), government subsidies are commonly provided. International experience indicates that the development of urban public transport systems is closely associated with sustained government financial support.

Various subsidy allocation methods exist, depending on the output indicators of transport services. In public bus transport, key output measures include passenger volume, passenger-kilometers (passenger-km), and the number of vehicle trips. Accordingly, several approaches can be applied to calculate subsidies [11]:

Subsidy based on passenger trips: The subsidy per passenger trip is determined by the difference between the cost-recovery fare and the regulated fare. The total subsidy is calculated based on the number of passenger trips and the subsidy per trip.

Subsidy based on vehicle trips: This method calculates subsidies based on the number of scheduled trips and the average subsidy per trip, which is defined as the difference between operating costs and average revenue per trip.

Combined subsidy based on passenger trips and vehicle-kilometers: Under this approach, subsidies are divided into two components:

- A passenger-based subsidy, calculated similarly to the first method but excluding capital depreciation costs, intended to cover direct operating expenses and financial returns.
- A distance-based subsidy (per vehicle-kilometer), reflecting depreciation costs and allocated to vehicle investment funds.

Currently, the subsidy mechanism applied in Ho Chi Minh City and, more broadly, in Vietnam is primarily based on the number of vehicle trips. While this method is simple and easy to implement - particularly under conditions where accurate passenger counting is difficult due to manual fare collection - it exhibits several limitations:

- It does not establish a strong link between subsidy levels and passenger demand, thereby providing limited incentives for operators to attract more users;
- It may lead to inefficiencies, where subsidies effectively compensate operational losses rather than directly benefiting passengers;
- The mismatch between operating costs and fare levels may create opportunities for inaccurate reporting of passenger volumes, particularly on low-demand routes, necessitating enhanced monitoring and supervision.

Under the current revenue-compensation model, fluctuations in passenger demand have limited impact on operator income. When demand decreases, reduced fare revenue is offset by increased subsidies; conversely, when demand increases, subsidies decrease, resulting in limited

financial incentives for operators to improve performance. This explains the lack of proactive measures by operators to increase ridership despite declining passenger volumes in recent years.

To address these issues, both the form and methodology of subsidy allocation should be reformed.

- **In terms of subsidy structure**, a fixed (contract-based) subsidy mechanism should replace the current revenue-compensation model. Under this approach, the government and operators agree in advance on a fixed subsidy per passenger trip based on operational parameters. This subsidy remains constant throughout the contract period.

- **In terms of calculation methodology**, it is necessary to clearly distinguish between the portion of subsidies allocated to operators (as a regulated profit component) and that allocated to passengers. The operator-related subsidy should be a fixed amount, disbursed upon fulfillment of planned service outputs (e.g., number of trips and kilometers operated), while the passenger-related subsidy should be directly linked to actual passenger volume.

Under this mechanism, operator revenue becomes directly dependent on ridership: higher passenger volumes result in higher income, while lower demand leads to reduced income. This creates stronger incentives for operators to improve service quality and attract passengers, while ensuring that subsidies are directed to the intended beneficiaries rather than being absorbed as operational compensation.

However, implementing a passenger-based subsidy mechanism requires accurate and reliable passenger counting to prevent revenue leakage and ensure accountability. Therefore, the application of information technology and advanced equipment is essential for automating data collection and revenue monitoring.

Technologies such as AFC systems, automatic passenger counting sensors, and CCTV surveillance systems are widely used to monitor and accurately measure passenger volumes in modern public transport systems.

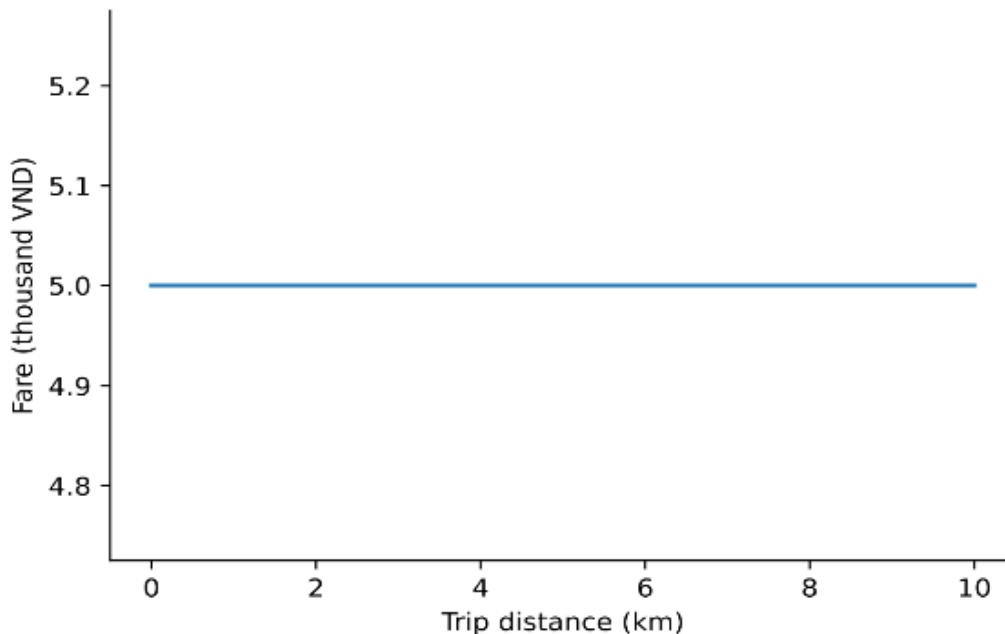


Figure 5. Diagram of the flat fare structure.

4.2. Fare pricing based on passenger travel distance

Currently, the fare policy for bus transport in Hà Nội and Ho Chi Minh City is based on a flat-fare structure applied across the entire network. Under this structure, the fare does not depend on trip distance, passengers are required to pay the same fare for all trips using public transport, regardless of whether they travel to the next stop or to the final stop of the route. As a result, this pricing scheme may not satisfy passengers making short-distance trips. In other words, this fare structure leads to cross-subsidization, where passengers undertaking longer trips are subsidized by those making shorter trips.

From the perspective of operators and management agencies, this fare structure shown in Figure 5 is convenient for management, the implementation of AFC systems, and fare adjustments over time. However, in order to set a uniform fare level, operators must consider various factors such as passenger demand, average trip length, and others to achieve appropriate revenue levels. A rational operational response to this fare structure is to reduce the duration of the applicable fare period or to segment trips into multiple fare zones or stages.

To ensure fairness for passengers and to mitigate the impacts of operators, many countries around the world recommend a distance-based fare structure, in which the fare is proportional to the travel distance.

Users are required to pay a base access fee upon entering the service (boarding fee), plus a variable cost calculated as the unit fare (per kilometer) multiplied by the trip length (in kilometers). In general, the distance-based fare calculation scheme can be summarized through the following formula and diagram in Figure 6

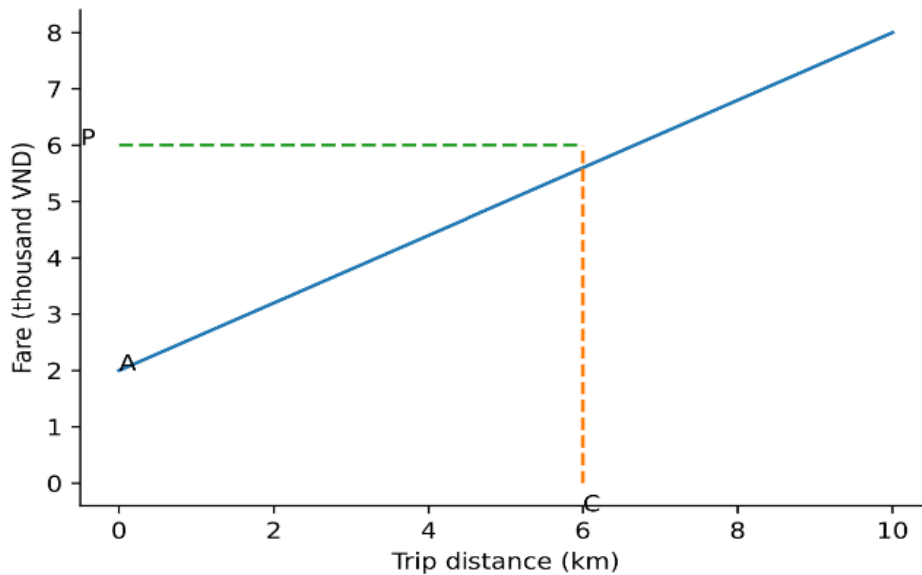


Figure 6. Diagram of the distance-based fare structure.

The fare structure is defined as:

$$P = A + B \times C \tag{1}$$

Where:

- P : total fare (thousand VND),
- A : fixed boarding charge (thousand VND),
- B : unit distance-based fare (thousand VND per kilometer),

- C: travelled distance (km).

This fare structure represents a linear distance-based pricing mechanism in which total fares increase proportionally with travel distance while including a fixed access charge. It is computationally simple, transparent, and perceived as relatively equitable since passengers pay in accordance with service usage. It also supports differentiated pricing in integrated or multimodal systems, where the fixed component (A) may be adjusted or waived to encourage transfers, while contributing to operator revenue stability.

However, such structures may introduce cognitive and administrative complexity, particularly in systems with zonal or heterogeneous tariffs. They may also generate equity concerns, as fare adjustments under cost inflation can disproportionately affect short-distance trips. These issues can be partially addressed through fare zoning or discretized fare bands to smooth price variations.

The application of AFC systems enhances the practical implementation of distance-based pricing by enabling accurate, real-time fare calculation based on travel data. This improves operational efficiency, transparency, and revenue integrity, while supporting more equitable and data-driven public transport pricing policies.

4.3. Fare Integration and Free Transfers Across Transport Modes

Fare integration across public transport modes, combined with free or discounted transfer policies, is a key mechanism for improving the efficiency and attractiveness of multimodal transport systems. This approach enables passengers to transfer seamlessly between services (e.g., bus, metro, and urban rail) within a defined transfer time window without incurring additional costs. An example of an integrated ticketing system implemented in Seoul is illustrated in Figure 7.

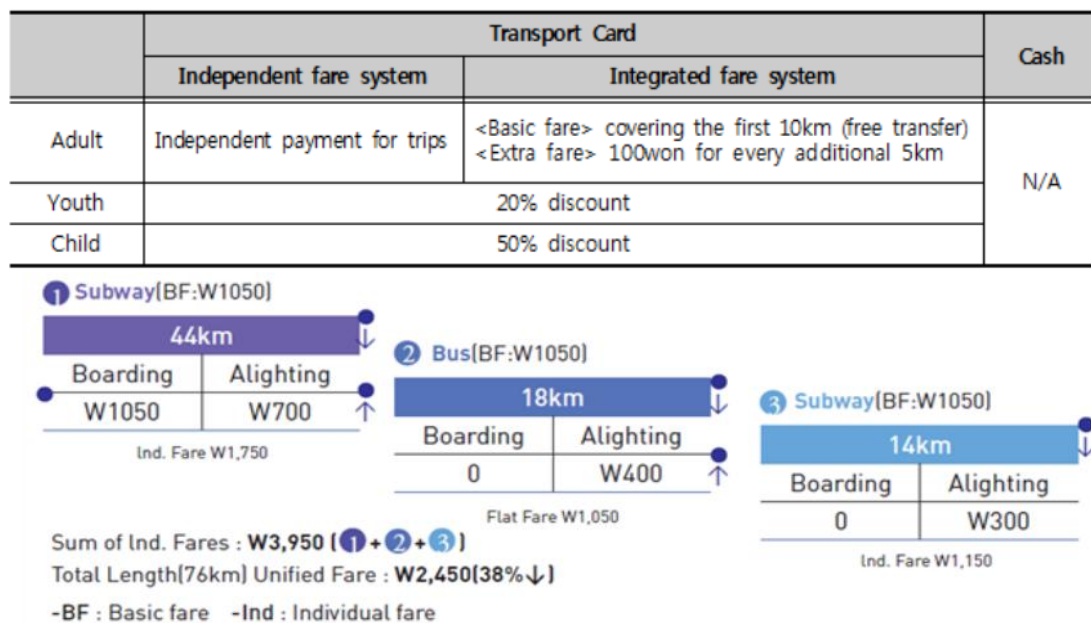


Figure 7. Integrated Fare Policy in Seoul.

From a policy perspective, fare integration reduces the generalized cost of multimodal trips by eliminating transfer-related financial penalties, thereby increasing the attractiveness of

public transport relative to private modes. This contributes to higher system accessibility and supports more coherent multimodal travel behavior in urban areas characterized by complex trip chaining.

From an operational perspective, implementing free transfer policies requires strong institutional coordination among transport operators, particularly regarding revenue allocation, fare clearing mechanisms, and data interoperability. Inadequate coordination may lead to revenue imbalance across operators, potentially undermining the financial sustainability of the system. In this context, AFC systems play a central enabling role. By providing time-stamped and trip-level travel data, AFC systems support the definition of transfer rules, enable automated fare reconciliation, and ensure transparent revenue distribution among operators. Consequently, AFC-based integration improves both operational efficiency and governance transparency in multimodal transport systems.

With advances in digital payment technologies, free or discounted transfers and integrated fare products have become increasingly feasible. Complementary incentive mechanisms, such as system-wide loyalty or reward schemes, can further enhance public transport attractiveness. However, successful implementation requires a fully integrated AFC infrastructure, centralized revenue management, and a clearing house mechanism for inter-operator settlement. In this regard, AFC systems should be developed toward full system interoperability, characterized by integrated data exchange, centralized governance, and real-time revenue processing. Such institutional and technological integration also provides a foundation for network restructuring strategies, including the development of trunk–feeder systems and strategically located transfer hubs, which enhance network efficiency, capacity utilization, and service quality.

4.4. Dynamic Adjustment of Operational Plans Based on Passenger Flow Variations

Effective public transport operations require service plans that closely reflect spatial and temporal variations in passenger demand. Traditionally, operational planning and adjustments rely on manual passenger surveys, which are costly, time-consuming, and often limited in accuracy and temporal resolution.

The adoption of AFC systems enables the continuous collection of high-resolution, real-time travel data. This allows operators to accurately monitor passenger flow patterns, including temporal distribution, directional flows, and trip distances, thereby improving the evidence base for operational decision-making [12, 13].

As a result, transport operators can adjust service frequency, routing, and capacity allocation in a more timely and demand-responsive manner. This enhances system efficiency and improves service alignment with actual travel demand patterns.

From a governance perspective, AFC-generated datasets provide transport authorities with a critical empirical foundation for policy formulation, system planning, and performance evaluation. These data contribute to improved regulatory oversight, enhanced decision-making efficiency, and more responsive public transport management.

Furthermore, AFC systems help mitigate revenue leakage, reduce fare evasion, and limit the occurrence of ticket fraud through automated and traceable transaction processing. Overall, AFC-based digitalization strengthens both operational efficiency and institutional capacity in public transport systems.

5. CONCLUSION

This paper redefines AFC systems not merely as payment tools, but as strategic digital infrastructures for improving the operation of public transport systems. By examining the components and development levels of AFC systems, the study highlights their broader functions in management, planning, and service optimization.

The paper also evaluates the current development of AFC systems in Hanoi and Ho Chi Minh City, identifying key limitations such as fragmentation, limited interoperability, and insufficient data utilization. Based on these findings, several solutions are proposed to enhance operational efficiency through the effective use of AFC-generated data.

Overall, cities should consider these issues when developing future AFC systems in order to fully exploit their technological potential and support more efficient, integrated, and sustainable public transport networks.

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