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Research Article

Influence of Mobile Payment on Bus Boarding Service Time

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A new form of mobile payment, Quick Response (QR) code, has been a popular way of paying bus fares in China since 2017. Compared with conventional payment methods, cash or IC card, QR code shows a lot of differences in response time, recognition accuracy, and payment procedure, which significantly influences the boarding service time (BST) for passengers. However, no research has considered its efficiency. This study, therefore, tries to fill this gap and investigate its influence on BST. Sufficient ride-check data were collected, and the influence of the QR code payment method on BST was examined through a set of regression models. Passengers pay the bus fare with different payment methods as their first choice; nevertheless, when the payment fails, they may transfer among them. According to the payment choice, result, and process, we introduce the first-choice-based, the last-choice-based, and the choice-transfer-based models, respectively. The scenario with delays in calling out the QR code was considered in the choice-transfer-based model. The onboard crowdedness was regarded as a categorical variable to determine the regime of the boarding process in all models. We conduct empirical analysis in Wuhan, and this study can help to identify the influence of the QR code payment method on BST, consequently, improving bus service efficiency.

1. Introduction

The smartphones have changed our daily life since they were invented in 1993 when IBM developed the first touchscreen phone named Simon with the Zaurus operating system. They provide easy access to information for people; taking the advanced traveler information system (ATIS) as an example, we can only get the information through conventional public media (variable message sign, electronic bus stop board, radio, and PC) in the past years, but now a map app (like Google Maps, Baidu Maps, and Gaode Maps) can provide useful travel information for travelers [1]. The android system of Google, the iOS system of Apple, and the Windows Phone system of Microsoft have promoted the rapid development of the smartphone market, and the ownership rate of smartphones has now risen to over half the population [2]. Besides the easy access to information, another change that smartphones brought to our daily life is mobile payment, which is booming in recent years and building a cashless world [3, 4]. It is quite common in China that you can pay for almost everything, including paying bus fares, by scanning the QR code of Alipay or WeChat Pay. In most situations, the efficiency or response time of QR code payment method is not seriously cared about; however, in a busy queuing system, like the boarding process at bus stops, the payment efficiency will influence the productivity, i.e., the increment of service time resulted from paying by QR code will prolong the total bus service time, and thus it cannot be neglected.

The QR code payment method for public transit in China is currently conducted by a preauthorized e-pass, which is bound with one's personal Alipay or WeChat Pay account. There are a considerable number of commuters paying bus fares by QR code every day. Compared with the conventional payment methods, such as cash and IC card (or smart card), differences do exist among them in response time, recognition accuracy, and convenience of usage. The QR code has its advantages, such as convenience, mobility, and hygiene, especially during the COVID-19 pandemic. From the perspective of commuters, convenience is the primary

concern that urge passengers to pay bus fares by QR code. People do not have to add money to their smart cards anymore, which not only saves time but also avoids the worries of the insufficient card balance. Besides, they do not have to bring one more card in addition to their mobile phones. However, the QR code payment method encounters a higher failure rate in reading because of the limitation of image recognition, and passengers are likely to experience a delay in calling out QR code when they step on buses, in case that they are doing other things instead of preparing the QR code during the waiting. This will increase the BST at stops, and the increment will lead to two severe problems for the bus transit system, reducing the utilization of bus stops because of the higher occupancy time of berths [5] and requiring more vehicles to fulfill the service plan due to the increment of vehicle turnover time [6]. In this regard, does the emerging QR code payment method prolong the BST? If the answer is "yes," how to improve it is of great concern for the transit operators, as the rapid development of mobile payment is unstoppable.

In this research, the influence of the QR code payment method on BST is examined from three aspects: the unit service time per boarding passenger paying by QR code, the influence of failure in reading QR code, and the influence of delay in calling out QR code. The contributions of this paper are threefold: first, this study is the first research to investigate the service efficiency of the emerging QR code payment method in the bus transit system. Second, we quantified the influence of the QR code payment method on BST, which explains why the efficiency of the QR code payment method is lower than that of the conventional payment methods. Third, we used the crowdedness to determine the regime of boarding processes, which differentiates the significance of independent variables under different scenarios and helps to analyze how the QR code payment method impacts on BST. The research results can provide specific guidance for related stakeholders to improve the service efficiency of the QR code payment method.

The remainder of this paper is organized as follows: in Section 2, we review the existing studies on bus BST at stops; in Section 3, we model the payment processes of boarding passengers and analyze the potential influence of QR code payment method on BST, and then dependent and independent variables are determined for regression analysis; in Section 4, the numerical analysis in different regimes is presented; and finally, Section 5 summarizes the main findings of the study and provides guidance for improving the service efficiency of the QR code payment method.

2. Literature Review

The operating time of bus services includes driving time between stops and dwell time at stops [7–9]. The dwell time at a bus stop, defined as the time spent by a bus at the bus stop for serving passenger alighting and boarding plus the time to open and close doors [10, 11], is a research focus in the bus transit system. As summarized in Meng and Qu's paper [11], the dwell time is a crucial component in transit operation and management; it can be used to estimate the capacity of a bus station, predict or estimate bus travel time, and bus dwell time plays a vital role in the transit assignment models and reliability analysis of the transit network. Besides, the deviation of dwell time caused by unbalanced passenger demand is widely agreed to be a major cause of the notorious bus bunching problem [12–25].

In the Transit Capacity and Quality of Service Manual (TCQSM) [5], factors that affect dwell time at stops consist of passenger boarding and alighting volumes, stop spacing, fare payment method, bus design, and in-vehicle circulation. To model bus dwell time, regression analysis was a popular method to examine the potential influence on dwell time of those factors [7, 8, 10, 26–36]. Levinson [7] proposed a linear regression model to explain the effect of the sum of passenger demand on dwell time. Guenthner and Hamat [26] assumed that dwell time is governed by the sum of boarding and alighting passengers and proposed a nonlinear model that contains two subfunctions for the number of passengers. Other than the passenger demand factor, researchers have analyzed the influence of some other factors on boarding and alighting time, for example, onboard crowdedness [8, 29–31, 34, 37–39], crowding at stop [31], bus design [31, 32, 34, 38], stop design [9–11, 31, 32], fare collection methods [30, 32, 33, 35, 37], time of day [33, 34], schedule adherence [34], queuing at stops [9, 11, 36], capacity limit [37], arterial traffic condition [9, 11], doors reopening action [11], and delay in taking out IC card [38]. Some researchers modeled the passenger behavior during buses serving at stops. Li et al. [40] developed a binary choice model to study passengers' preference for the front or back door when alighting and applied the model to estimate dwell time. Zhou et al. [41] developed a series of models to predict passenger demands on bus service when the in-vehicle crowdedness information is available for boarding passengers. Besides, the influence on dwell time is not always considered from the perspective of efficiency but stability. Ji et al. [42] adopted a social force model and multiagent-based approach to analyze the dynamic process of boarding and alighting passengers, and they found that enlarging the platform area and installing guide guardrails can observably reduce the variation in bus dwell time, but not the length of the time itself, so it cannot improve the service efficiency but provide a more comfortable environment for passenger boarding and alighting.

BST is the time cost for serving the boarding passengers, and it is a major part of the dwell time at stops, because the unit service time for a boarding passenger is usually much longer than that for an alighting passenger [8, 9, 11, 26, 28–30, 33–38]. The BST is determined by the boarding demand, i.e., the number of boarding passengers, and the service efficiency, i.e., the unit service time per boarding passenger. The boarding demand is determined by the arrival rate of passengers and the service frequency of the bus route. When the service plan is determined, the number of boarding passengers is determined as well. Hence, to a large extent, the BST is determined by the unit service time. In previous research, the calibrated unit service time ranges from 1.36 s [11] to as high as 5.66 s [26], and the most recognized value is between 2 s and 3 s [5–7, 9, 28, 29, 37, 38]. The

onboard crowdedness [8, 29–31, 34, 37–39], the bus design [31, 32, 34, 38], and the fare collection method [30, 32, 33, 35, 37] are the three main factors affecting the unit service time. The onboard crowdedness influences the friction between boarding passengers and onboard passengers, and the unit service time increases with the rise of onboard crowdedness. The bus design influences the effort needed for boarding passengers to step on the bus, and a low-floor vehicle can reduce the unit service time. The fare collection method influences the payment time of boarding passengers, and different payment methods result in a great variation of the unit service time. In Guenthner and Hamat's research [26], the bus fare was paid by cash, and the unit service time (5.56 s/pax) is quite long. Besides, an extreme case that as high as 20.8 s for a boarding passenger was observed in their research. Martin [30] reported a longer time for boarding passengers paying by cash (4.26 s/pax) than paying by smart card (3.10 s/pax) in a hybrid fare collection system. In Sun et al.'s research [38], the smart card system was introduced in Singapore in April 2002, and it then covered 97% of the total transit trips in 2008. The unit service time of paying by IC card was only 2 s in their research.

During the past three years in China, the explosive boosting of mobile payment technology has provided a new fare collection method for the bus system, i.e., paying the bus fare by QR code, and it is expected to be more and more popular because of its convenience, i.e., passengers do not need to carry an IC card or cash, and safety, i.e., they are no longer worried about losing the card or money. Differences do exist between the emerging QR code payment method and the conventional IC card payment method for three main reasons. First, the reading of the QR code is based on image recognition, while the reading of the IC card is based on telecommunication. Second, the QR code needs to be well prepared before paying the bus fare, and the time cost for calling out the QR code cannot be ignored. In daily life, passengers are likely to use their smartphones to do other businesses when waiting for the bus, and this may result in delays in calling out QR code when they step on the bus. Third, a much more demanding environment is needed for reading the QR code; for example, the QR code should be directly facing the camera, the QR code cannot be either too close to or too far away from the camera, the brightness of the QR code should be enough, and so on; otherwise, it cannot be correctly recognized. So, the failure rate in reading the QR code is higher than that in reading the IC card. Therefore, the service efficiency of the QR code payment method is lower than conventional payment methods, especially the IC card. Accordingly, we want to find out how much the efficiency difference is. The research results will help to improve the bus service efficiency under the new hybrid fare collection contexts.

3. Methodology

3.1. Payment Process. With the popularization of mobile payment in China, nowadays there are three mainstream payment methods for paying the bus fare, by cash, by IC card, and by QR code (see Figure 1).

Figure 1: The fare collection methods of the bus transit system in China.

When a passenger boards on a bus, she/he may choose her/his preferred payment method to pay the bus fare. In our survey, 1709 boarding passengers were recorded; only 74 passengers (4.33%) choose to pay the bus fare by cash as their first choice, 1169 passengers (68.40%) choose to pay the bus fare by IC card as their first choice, which is the dominant payment method, and 466 passengers (27.27%) choose to pay the bus fare by QR code as their first choice, the second large share of the market (see Figure 2).

For boarding passengers paying by cash as their first choice, they do not encounter any failures in the paying process, while both the IC card and the QR code have the risk of paying failure during the paying process. In our survey, 2.40% of boarding passengers paying by IC card and 19.96% of boarding passengers paying by QR code encounter failures (see Figure 2). Generally, for the IC card, the failures are caused by insufficient card balance. While for the QR code, the failures are due to two reasons: first, the QR code is wrong, as some passengers may misuse their payment code as the e-pass code; second, there is an error in scanning the QR code.

When the payment with IC card or QR code fails, passengers may transfer to alternative payment methods. Theoretically, when the payment with IC card fails, the passenger can transfer to QR code or cash; while when the payment with QR code fails, the passenger may scan the QR code again or transfer to IC card or cash. According to our survey, passengers made the following choices actually (see Figure 2): (1) transfer from IC card to cash (22 cases of 28 failures, 78.57%) or QR code (6 cases of 28 failures, 21.43%) when the money in IC card is insufficient and (2) try to scan the QR code again (78 cases of 93 failures, 83.87%) or transfer from QR code to cash (15 cases of 93 failures, 16.13%) when the QR code fails in reading at the first time. No passenger failed in paying by QR code transfers to IC card; the explanation should be that if the passenger carries an IC card, she/he will pay the bus fare by the IC card as the first choice.

Finally, 111 passengers (6.50%) pay the bus fare effectively by cash, 1141 passengers (66.76%) by IC card, and 457 passengers (26.74%) by QR code (see Figure 2).

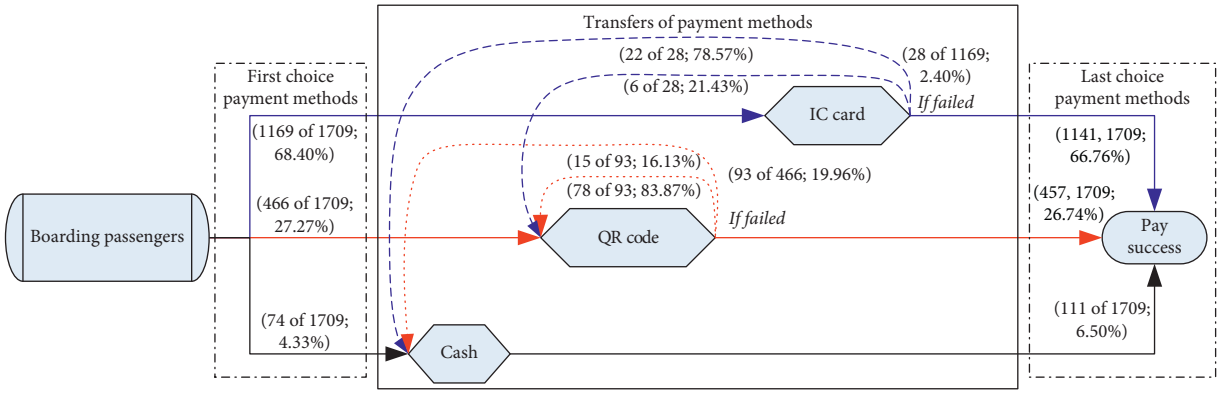

Figure 2: The share of different payment methods.

3.2. Impact Factors in the QR Code Payment Method. Response time, failure in QR code reading, and delay in calling out QR code are the three main factors in the QR code payment method that influence BST. The response time for scanning QR code affects the BST, as a faster response rate will improve the boarding efficiency. The QR code payment method may encounter failure in reading QR code, which causes additional time for passengers to scan the QR code again or transfer to other payment methods. According to our survey, there were 93 cases of failure in QR code reading within a total of 466 QR code payments as the first choice, and the possibility is 19.96%. The situation of delay in calling out the QR code will also result in extra time for passengers to prepare the QR code when boarding on vehicles. In the survey, 154 cases of delay in calling out QR code were recorded, and the possibility is as high as 33.05%. More specifically, we distribute the frequency and the cumulative frequency distributions of the delays in calling out QR code with all boarding passengers, and the results show that the situation of delay in calling out QR code occurs most frequently with the boarding demand of 4 and 5 passengers (see Figure 3(a)), and around 90% of them happens when the boarding demand is less than 9 passengers (see Figure 3(b)). An explanation for this phenomenon is that when the queue of boarding passengers is short, the boarding interval between passengers is not long enough for passengers to call out the QR code before they step on the bus.

3.3. Regression Modeling. To identify the influence of the emerging QR code payment method on BST, the linear regression model was adopted in this research.

The BST at stops was chosen as the independent variable. It is the time interval between the first and the last boarding passenger stepping on the bus. Similar to the research conducted by Sun et al. [38], N boarding passengers have $N-1$ service intervals, and the boarding service time with only one boarding passenger is assumed as zero.

To model the influence of the QR code payment method in the hybrid fare collection system, we established three regression models. They are derived from the paying process in Figure 2, in which passengers' choice of payment methods in the hybrid fare collection system can be explained from three perspectives: their willing or first choice of payment methods, their eventual or effective choice of payment methods, and their choice transfer of payment methods during the paying process. The first one is defined as the first-choice-based model, in which the boarding passengers with different payment methods as their first choice were considered. The second one is referred to as the last-choice-based model, in which the boarding passengers with different payment methods eventually were considered. To be noted, we differentiate the first-choice-based and the last-choice-based models as the first-choice payment method may fail in paying the bus fare, but for most passengers, the eventual payment method is their first-choice one, as the failure rate for all passengers is only 7.08% (121 cases of 1709 passengers). The third one is called the choice-transfer-based model, in which we consider the transfer among payment methods during the paying process, in other words, transferring from one payment method to another when passengers fail in paying the bus fare. Furthermore, the friction among boarding and onboard passengers has shown its importance in determining BST in the literature [8, 29–31, 34, 37–39], and there are two ways to deal with the in-vehicle crowdedness (or occupancy), considering it as an independent variable [8, 29, 31, 34, 37, 39] or applying it to determine the regime of boarding process [30, 38]. In this research, we treat the in-vehicle crowdedness as a category variable to determine the regime of models, which identifies whether and how the delay in calling out QR code and the failure in reading QR code influence BST. As the effect of in-vehicle crowdedness on BST is the resistance of passengers during the boarding process, which is active only if the occupancy reaches a certain level, we define the level of in-vehicle crowdedness to be 0 if the boarding process is smooth, and 1 otherwise.

3.3.1. First-Choice-Based Regression Model. In the first-choice-based model, we consider the number of boarding passengers by different payment methods as their first choice, i.e., cash, IC card, and QR code. That is to say,

$$\mathrm{BST}_1 = c_1 + \alpha_1 \mathrm{IC}^0 + \beta_1 \mathrm{QR}^0 + \gamma_1 \mathrm{Cash}^0, \quad (1)$$

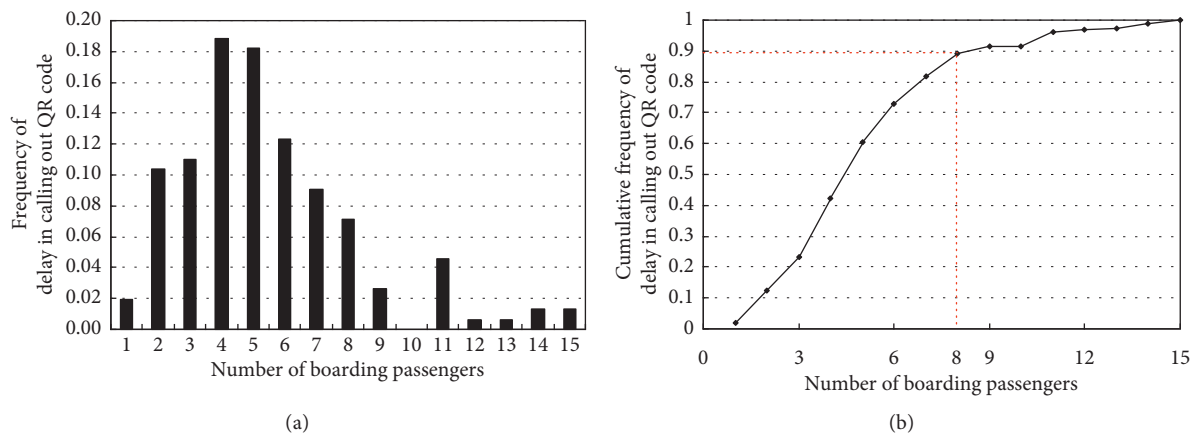

Figure 3: The distribution of the delay in calling out QR code with the boarding demand. (a) Frequency of delay vs. number of boarding passengers. (b) Cumulative frequency of delay vs. number of boarding passengers.

where IC^0, QR^0, and $Cash^0$ are the numbers of passengers paying by IC card, QR code, and cash as their first choice, α_1, β_1, and γ_1 are the unit service time of paying by IC card, QR code, and cash as her/his first choice, c_1 is the constant or intercept of the model, and the subscript of the parameter is the indicator of the model number.

3.3.2. Last-Choice-Based Regression Model. In the last-choice-based model, we consider the number of boarding passengers paying the bus fare effectively by different payment methods, i.e., cash, IC card, and QR code. That is to say,

$$BST_2 = c_2 + \alpha_2 IC^1 + \beta_2 QR^1 + \gamma_2 Cash^1, \quad (2)$$

where IC^1, QR^1, and $Cash^1$ are the numbers of passengers paying the bus fare effectively by IC card, QR code, and cash, α_2, β_2, and γ_2 are the unit service time of paying by IC card, QR code, and cash effectively, c_2 is the constant or intercept of the model, and the subscript of the parameter is the indicator of the model number.

3.3.3. Choice-Transfer-Based Regression Model. As shown in Figure 2, passengers paying by IC card or QR code as their first choice are possible to fail, and then they have to transfer to alternative payment methods, such as cash. According to the choices of transfer among payment methods, passengers paying the bus fare as their first choice or last choice can be distinguished into passengers with different paying processes.

The number of boarding passengers paying by IC card as their first choice, namely, IC^0, can be divided into the number of passengers paying by IC card effectively and the number of passengers transferring from IC card to cash (defined as IC-Cash) and QR code (defined as IC-QR) when they encounter failures in IC card reading. They have the following relationship:

$$IC^0 = IC^1 + IC - Cash + IC - QR. \quad (3)$$

The number of boarding passengers with the first choice of QR code, namely, QR^0, can be divided into the number of passengers paying by QR code with only one scanning (defined as QR-Once) and with more than one scanning (defined as QR-QR) and the number of passengers transferring from QR code to cash (defined as QR-Cash). They have the following relationship:

$$QR^0 = QR - Once + QR - QR + QR - Cash. \quad (4)$$

Passengers paying by cash as their first choice will not fail at all; however, passengers paying by cash effectively can be not only from those paying by cash as their first choice but also from those transferring from IC card or QR code. Hence, the number of boarding passengers paying by cash effectively, namely, $Cash^1$, can be divided into the number of passengers paying by cash as their first choice ($Cash^0$), the number of passengers transferring from IC card to cash (IC-Cash), and the number of passengers transferring from QR code to cash (QR-Cash). They have the following relationship:

$$Cash^1 = Cash^0 + IC - Cash + QR - Cash. \quad (5)$$

Similarly, the number of boarding passengers paying by QR code effectively, namely, QR^1, can be divided into the number of passengers paying by QR code as their first choice with only one scanning (QR-Once) and with more than one scanning (QR-QR) and the number of passengers transferring from IC card to QR code (IC-QR). They have the following relationship:

$$QR^1 = QR - Once + QR - QR + IC - QR. \quad (6)$$

Passengers paying by IC card effectively are only from those paying by IC card as their first choice, since no passenger paying by cash as her/his first choice fails and no passenger paying by QR code as her/his first choice transfers to IC card when she/he fails.

The total number of boarding passengers is equal to the sum of boarding passengers with different first-choice payment methods, the sum of boarding passengers paying

the bus fare effectively by different payment methods, and the sum of passengers paying the bus fare with different paying processes; that is,

$$\begin{aligned} B &= \mathrm{IC}^0 + \mathrm{QR}^0 + \mathrm{Cash}^0 = \mathrm{Cash}^1 + \mathrm{QR}^1 + \mathrm{IC}^1 \\ &= \mathrm{IC}^1 + \mathrm{IC} - \mathrm{Cash} + \mathrm{IC} - \mathrm{QR} + \mathrm{QR} - \mathrm{Once} + \mathrm{QR} - \mathrm{QR} \\ &\quad + \mathrm{QR} - \mathrm{Cash} + \mathrm{Cash}^0, \end{aligned} \tag{7}$$

where B is the total number of boarding passengers.

Therefore, in the choice-transfer-based model, we categorize the boarding passengers into 7 groups, namely, Cash^0, IC-Cash, QR-Cash, IC^1, QR-Once, QR-QR, and IC-QR, according to their different paying processes. Since the boarding passengers paying by QR code have been distinguished, it cannot be further divided into passengers with and without delay in calling out QR code; otherwise, it will make the boarding passengers paying by QR code double counting. With this consideration, the number of delays in calling out the QR code is introduced into the choice-transfer-based model as an additional independent variable.

The established choice-transfer-based model for BST analysis is as follows:

$$\begin{aligned} \mathrm{BST}_3 &= c_3 + \alpha_3 \mathrm{IC}^1 + \beta_3^1 \mathrm{QR} - \mathrm{Once} + \beta_3^2 \mathrm{QR} \\ &\quad - \mathrm{QR} + \beta_3^3 \mathrm{IC} - \mathrm{QR} + \gamma_3^1 \mathrm{Cash}^0 + \gamma_3^2 \mathrm{QR} - \mathrm{Cash} \\ &\quad + \gamma_3^3 \mathrm{IC} - \mathrm{Cash} + \delta_3 \mathrm{Delays}, \end{aligned} \tag{8}$$

where α_3 is the unit service time of paying by IC card effectively; β_3^1, β_3^2, and β_3^3 are the unit service time of paying by QR code with only one scanning, paying by QR code with more than one scanning, and transferring from IC card to QR code, respectively; and γ_3^1, γ_3^2, and γ_3^3 are the unit service time of paying by cash as her/his first choice, transferring from QR code to cash, and transferring from IC card to cash, respectively. δ_3 is the effect of delay in calling out QR code each time, c_3 is the constant or intercept of the model, and the subscript of the parameter is the indicator of the model number.

The detailed descriptions of all variables are shown in Table 1.

4. Numerical Analysis

4.1. Data Preparation. There are two widely used survey methods in the bus transit system [6]. One is the ride-check survey, in which investigators are traveling in the vehicle to record data, and the other is the stop-check survey, in which investigators are placed at the stop to record data. We chose the ride-check survey because the failure in reading IC card or QR code and the situations of delay in calling out QR code are hard to distinguish by the stop-check survey, especially during peak hours when the queue of boarding passengers is long. Two graduate students participated in the task of surveying one bus: one records the time when the bus front door opens and closes and the time when the first and the last passenger step on the vehicle, and the other student counts the number of boarding passengers by different fare payment methods and records the events, such as the transfer among payment methods when passengers encounter failure in paying by IC card or QR code, and the delay in calling out QR code. As stated in Section 3, the factors that affect the QR code payment method on BST are response time, failure in QR code reading, and the delay in calling out the QR code. The response time for QR code recognition is hidden in the unit service time and cannot be recorded directly, but it can be derived from the following models. The failure in QR code reading can be recorded by the warning tone "Error in reading the QR code!" As to the delay in calling out QR code, it was recorded by the judgment that whether the boarding passenger is well prepared for QR code scanning when she/he steps on the vehicle.

The survey was done on buses of Line 540 in Wuhan, China, which travels between Wuhan Railway Station and Wuchang Railway Station, and the survey was conducted during the rush hours in July 2019. The reason why we choose the rush hours instead of the whole operation time of the bus route is that we must make sure that there are enough boarding passengers when buses arrive at stops; otherwise, a lot of BST at stops is zero if there is no or only one boarding passenger. In our survey, 469 samples with boarding demand were recorded, in which 71 samples have only one boarding passenger and the BST of them is assumed to be zero. Those samples are inappropriate for the regression analysis because there is no sensitivity for independent variables. Finally, 398 samples with more than one boarding passenger were used for the regression analysis.

All the regression models in the following are gained by the multiple linear regression (MLR) models in the SPSS and by the stepwise regression method, and we choose the last-step model for results analysis.

4.2. Model Results

4.2.1. First-Choice-Based Regression Model. The first-choice-based BST model shows the average service time for one boarding passenger using different payment methods as her/his first choice, and the regression results are shown in Table 2.

In the first-choice-based BST models, all the first-choice payment methods have passed the significant test, no matter under the crowded condition or not, and the established first-choice-based models under different scenarios are presented as follows:

$$\mathrm{BST}_1 = \begin{cases} 1.62 + 1.70\mathrm{IC}^0 + 3.44\mathrm{QR}^0 + 1.49\mathrm{Cash}^0, & \text{uncrowded}, \\ 0.86 + 2.20\mathrm{IC}^0 + 3.72\mathrm{QR}^0 + 2.34\mathrm{Cash}^0, & \text{crowded}. \end{cases} \tag{9}$$

Therefore, we can draw the following conclusions.

First, the service efficiency of the QR code as the first choice is much lower than that of cash or IC card as the first choice under both uncrowded and crowded conditions. The unit service time for passengers paying by QR code as their first choice is always longer than that paying by cash or IC card as their first choice, but the range is different under

Table 1: Descriptions of the variables in regression models.

Variables		Description	Models
Dependent	BST	The boarding service time	1, 2, 3*
Independent	$Cash^0$	The number of passengers paying by cash as their first choice	1, 3
	IC^0	The number of passengers paying by IC card as their first choice	1
	QR^0	The number of passengers paying by QR code as their first choice	1
	$Cash^1$	The number of passengers paying by cash effectively	2
	IC^1	The number of passengers paying by IC card effectively	2,3
	QR^1	The number of passengers paying by QR code effectively	2
	IC-Cash	The number of passengers transferring from IC card to cash	3
	IC-QR	The number of passengers transferring from IC card to QR code	3
	QR-Cash	The number of passengers transferring from QR code to cash	3
	QR-Once	The number of passengers paying by QR code as their first choice with only one scanning	3
	QR-QR	The number of passengers paying by QR code as their first choice with more than one scanning	3
	Delays	The number of passengers with delay in calling out QR code	3
	Crowdedness	Level of in-vehicle crowdedness when buses arrive at stops	1, 2, 3

*1 represents the *first-choice-based model*, 2 represents the *last-choice-based model*, and 3 represents the *choice-transfer-based model*.

Table 2: First-choice-based BST regression analysis.

Regime	Model	B	t	Sig.	Adjusted R^2	Std. errors
Crowdedness = 0	(Constant)	1.62	2.52	0.01	0.63	3.24
	QR^0	3.44	9.95	0.00		
	IC^0	1.70	9.72	0.00		
	$Cash^0$	1.49	3.21	0.00		
Crowdedness = 1	(Constant)	0.86	1.77	0.08	0.72	3.63
	QR^0	3.72	19.57	0.00		
	IC^0	2.20	19.08	0.00		
	$Cash^0$	2.34	4.56	0.00		

different scenarios. More specifically, the unit service time of paying by QR code as her/his first choice is about 2.03 times of that paying by IC card and 2.31 times of that paying by cash under uncrowded condition and 1.69 times of that paying by IC card and 1.59 times of that paying by cash under crowded condition.

Second, the friction among boarding and onboard passengers impairs the service efficiency of all payment methods as the first choice and prolongs the unit service time. Under the crowded condition, the unit service time of paying by IC card and cash as her/his first choice is 1.30 and 1.58 times, respectively, of that under uncrowded condition. However, the unit service time of paying by QR code as their first choice under crowded condition is almost the same as, only about 1.08 times of, that under uncrowded condition. Maybe the influence of the QR code payment method on BST has different mechanisms under uncrowded and crowded conditions, since we have not explicitly considered the influence on BST of the situation of delay in calling out QR code and the failure in QR code reading.

Third, the service efficiency of the cash as the first choice is higher than that of the IC card as the first choice under the uncrowded condition but lower under the crowded condition. The unit service time of paying by cash as the first choice is 0.21 s shorter than that paying by IC card as the first choice under the uncrowded condition, but 0.14 s longer than that paying by IC card as the first choice under the crowded condition. It might because the fare of the ticket is uniform, 2 RMB for a single trip, and passengers paying by cash as their first choice are well prepared for the bus fare during the waiting, which results in the shorter service time of the cash payment method. Besides, passengers paying by IC card as their first choice may encounter failure during the paying process. Although the possibility is not very high (2.40%), it can also lead to longer service time. Meanwhile, there are differences in the influence of friction among boarding and onboard passengers on the service efficiency of different payment methods, and the unit service time of paying by cash as the first choice increases more, about 57.53%, than those paying by IC card as their first choice, about 29.62%, from the uncrowded condition to the crowded condition.

4.2.2. Last-Choice-Based Regression Model. The last-choice-based BST model shows the average service time for one boarding passenger paying the bus fare effectively by different payment methods, and the regression results are shown in Table 3.

In the last-choice-based BST models, all the payment methods that pay for the bus fare effectively have passed the significant test under both the crowded and the uncrowded conditions, and the established last-choice-based BST models under different scenarios are presented as follows:

$$BST_2 = \begin{cases} 1.74 + 1.52IC^1 + 3.54QR^1 + 2.64Cash^1, & \text{uncrowded}, \\ 0.47 + 2.15IC^1 + 3.67QR^1 + 4.60Cash^1, & \text{crowded}. \end{cases} \quad (10)$$

Table 3: Last-choice-based BST regression analysis.

Regime	Model	B	t	Sig.	Adjusted R^2	Std. errors
Crowdedness = 0	(Constant)	1.74	2.76	0.01	0.64	3.21
	QR[1]	3.54	9.79	0.00		
	IC[1]	1.52	8.59	0.00		
	Cash[1]	2.64	6.41	0.00		
Crowdedness = 1	(Constant)	0.47	1.01	0.31	0.74	3.48
	QR[1]	3.67	20.22	0.00		
	IC[1]	2.15	19.31	0.00		
	Cash[1]	4.60	11.18	0.00		

The results can be summarized as follows.

First, the service efficiency of the QR code is no longer lower than cash and IC card all the time. Under the uncrowded conditions, the QR code has the lowest service efficiency, and the unit service time of paying by QR code is 2.33 times of that paying by IC card and 1.34 times of that paying by cash. Under the crowded condition, the service efficiency of the QR code is lower than the IC card but higher than cash, and the unit service time of paying by QR code is 1.71 times of that paying by IC card but 80% of that paying by cash.

Second, the service efficiency of paying by cash is much lower than that of paying by IC card, as the unit service time of paying by cash is 1.74 times of that paying by IC card under the uncrowded condition and 2.14 times of that paying by IC card under the crowded condition. The main reason for the sharp decline of the service efficiency of paying by cash is that some passengers failed in paying by IC card or QR code as their first choice transfer to the cash, and it costs a lot of time for them to look for the money, as people in China are accustomed to a cashless life.

Third, the friction among boarding and onboard passengers impairs the service efficiency of all payment methods and prolongs the unit service time. Under the crowded condition, the unit service time of paying by IC card and cash is 1.41 and 1.74 times, respectively, of that under the uncrowded condition. However, the unit service time of paying by QR code under the crowded condition is almost the same as, only about 1.04 times of, that under the uncrowded condition.

4.2.3. Comparisons between the First-Choice-Based and the Last-Choice-Based Models. It should be noted that, when there is no QR code payment method, the first-choice-based model will be almost the same as the last-choice-based model, as passengers seldom fail in paying by cash or IC card as their first choice. So, in previous research, no researcher has differentiated the first-choice and the last-choice payment methods in a hybrid fare collection system with cash, IC card, magnetic stripe, monthly ticket, and so on [5, 28, 30, 32, 35, 37]. However, in the new hybrid fare collection system with cash, IC card, and QR code, the first-choice-based and the last-choice-based models are different because passengers paying by IC card and QR code as their first choice will transfer to alternative payment methods when the first-choice payment method fails (see Figure 4).

Comparing the first-choice-based model and the last-choice-based model, we can find the following.

First, for passengers paying by cash as their first choice, which is also their effective fare payment method, the unit service time is 1.49 s under the uncrowded condition and 2.34 s under the crowded condition. For passengers paying by cash effectively, however, the unit service time is as high as 2.64 s under the uncrowded condition and 4.60 s under the crowded condition, almost twice of that in the first-choice-based model. The reason should be that most, nearly 80%, of passengers failed in paying by IC card and all the passengers failed in paying by QR code transfer to the cash, which prolongs the unit service time. In previous research, the calibrated unit service time of paying by cash varies greatly [5, 26, 30, 32, 37]. On the one hand, the regime of fare may be different between bus routes; some routes have multistage fares [26], and some routes have a uniform fare [32], which results in the variation of service time paying by cash. On the other hand, the choice transfer among payment methods in a hybrid fare collection system [5, 28, 30, 32, 35, 37], such as transferring from IC card to cash when the IC card fails in paying the bus fare, has not been explicitly considered in previous research.

Second, for passengers paying by IC card effectively, which is also their first-choice fare payment method, the unit service time per boarding passenger is 1.52 s under the uncrowded condition and 2.15 s under the crowded condition, while for passengers paying by IC card as their first choice, the unit service time is 1.70 s under uncrowded condition and 2.20 s under crowded condition, a little higher than that in the last-choice-based model. The reason is the failure rate of the IC card is very low, only about 2.40%, and the transfer from IC card to QR code or cash has not prolonged too much the unit service time of IC card in the first-choice-based model. The calibrated unit service time of paying by IC card is in accord with the most recognized value, about 2-3 s, in previous research [5–7, 9, 28, 29, 37, 38].

Third, for passengers paying by QR code as their first choice, the unit service time is 3.44 s under the uncrowded condition and 3.72 s under the crowded condition, while for passengers paying by QR code effectively, the unit service time is 3.54 s under the uncrowded condition and 3.67 s under the crowded condition. The efficiencies of the QR code in the first-choice-based model and the last-choice-based model are almost the same; that is because few, only 3.22%, of passengers paying by QR code as their first choice

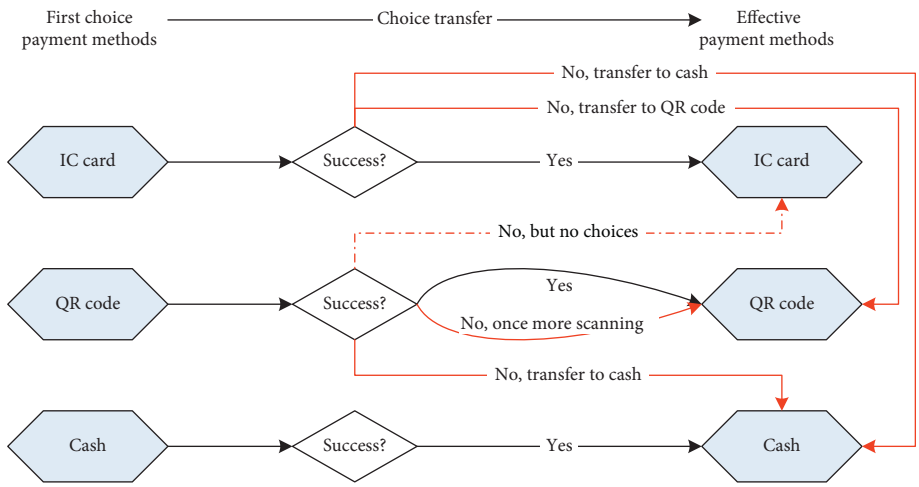

FIGURE 4: The choice transfer among different payment methods.

transfer to cash when they fail in QR code reading, and few, only 1.31% , of passengers paying by QR code effectively transfer from IC card when they fail in IC card reading. This finding is similar to the IC card, as its efficiencies in the first-choice-based model and the last-choice-based model are almost the same, since 97.60% of passengers paying by IC card as their first choice are the ones paying by IC card effectively. It should be noted that the unit service time of the QR code increases only a little from the uncrowded condition to the crowded condition, by 0.28 s (8%) in the first-choice-based model and 0.13 s (4%) in the last-choice-based model. However, the unit service time of paying by IC card effectively (IC^1) increases by 0.63 s (41%) and the unit service time of the cash as the first choice ($Cash^0$) increases by 0.85 s (57%) from the uncrowded condition to the crowded condition. Probable reasons are that the influence of delay in calling out QR code and failures in QR code reading on BST has been explicitly derived in the first-choice-based and the last-choice-based models. Therefore, we propose the following choice-transfer-based model, which helps to diagnose the reasons why the service efficiency of the QR code is only slightly higher under the uncrowded condition than the crowded condition.

4.2.4. Choice-Transfer-Based Regression Model. As mentioned in the Methodology part, passengers paying by QR code or IC card as their first choice may encounter failures in QR code reading or IC card reading, so in the choice-transfer-based model, we use QR-Once, QR-QR, and QR-Cash to replace the boarding passengers paying by QR code as their first choice (QR^0) and IC^1, IC-QR, and IC-Cash to replace the boarding passengers paying by IC card as their first choice (IC^0). The boarding passengers paying by cash as their first choice ($Cash^0$) are kept in the choice-transfer-based model, and the number of delays in calling out QR code (Delays) is introduced in the choice-transfer-based model. The regression results are shown in Table 4.

In the choice-transfer-based BST models, almost all concerned independent variables have passed the significant test under both crowded and uncrowded conditions, except the variable "Delays," which is only significant under the uncrowded condition. The established choice-transfer-based models under different scenarios are listed as follows:

$$BST_3 = \begin{cases} 1.24 + 1.60IC^1 + 2.72QR - Once + 3.92QR - QR + 5.60IC - QR + \\ 1.54Cash^0 + 5.18QR - Cash + 7.89IC - Cash + 1.99Delays, \quad \text{Uncrowded}, \\ 1.31 + 1.99IC^1 + 3.11QR - Once + 4.53QR - QR + 4.77IC - QR + \\ 2.39Cash^0 + 9.49QR - Cash + 8.92IC - Cash, \quad \text{Crowded}. \end{cases} \tag{11}$$

From the regression results, we can generate the following conclusions.

First, the service efficiency of the QR code is indeed lower than that of cash and IC card. The unit service time of paying by QR code with one scanning (QR-Once) is about 1.70 times of that paying by IC card effectively (IC^1) and 1.76 times of that paying by cash as her/his first choice (IC^0) under the uncrowded condition and 1.56 times of that paying by IC card effectively (IC^1) and 1.30 times of that paying by cash as her/his first choice (IC^0) under the crowded condition.

Second, it should be noted that compared with passengers paying by QR code with only one scanning (QR-Once), the unit service time of paying by QR code with more

Table 4: Choice-transfer-based BST regression analysis.

Regime	Model	B	t	Sig.	Adjusted R^2	Std. errors
Crowdedness = 0	(Constant)	1.24	2.30	0.02	0.75	2.67
	IC^1	1.60	10.55	0.00		
	QR-Once	2.72	5.71	0.00		
	IC-Cash	7.89	7.54	0.00		
	QR-QR	3.92	5.20	0.00		
	QR-Cash	5.18	5.02	0.00		
	$Cash^0$	1.54	3.99	0.00		
	IC-QR	5.60	3.53	0.00		
	Delays	1.99	2.37	0.02		
Crowdedness = 1	(Constant)	1.31	3.13	0.00	0.81	3.04
	IC^1	1.99	20.13	0.00		
	QR-Once	3.11	15.44	0.00		
	QR-QR	4.53	13.59	0.00		
	IC-Cash	8.92	11.58	0.00		
	QR-Cash	9.49	8.01	0.00		
	$Cash^0$	2.39	5.55	0.00		
	IC-QR	4.77	2.69	0.01		

than one scanning (QR-QR) is 1.20 s longer under the uncrowded condition and 1.42 s longer under the crowded condition, that is, the additional time for scanning the QR code again, or even several more times until it succeeds.

Third, per delay in calling out QR code (Delays) contributes 1.99 s to the BST under the uncrowded condition, which prolongs the unit service time of all passengers paying by QR code as their first choice; however, the delay in calling out QR code is insignificant under the crowded condition, a reasonable explanation should be that the crowdedness often happens in rush hours, so passengers in the boarding queue have enough time to call out the QR code before stepping on the bus.

Fourth, when passengers paying by IC card or QR code as their first choice but encounter failure in the paying process, the service time increases sharply. More specifically, when the passenger transfers from paying by IC card as her/his first choice to paying by cash effectively, it costs 7.89 s under the uncrowded condition and 8.92 s under the crowded condition; when the passenger transfers from paying by QR code as her/his first choice to paying by cash effectively, it costs 5.18 s under the uncrowded condition and 9.49 s under the crowded condition; when the passenger transfers from paying by IC card as her/his first choice to paying by QR code effectively, it costs 5.60 s under the uncrowded condition and 4.77 s under the crowded condition. It is more time-consuming for passengers to transfer from paying by QR code or IC card, but failed, to paying by cash eventually because transit riders in China are accustomed to the cashless payment method for paying the bus fare.

Finally, the friction among boarding and onboard passengers impairs the service efficiency of all payment methods and prolongs the unit service time. Under the crowded condition, the unit service time of paying by IC card effectively (IC^1) and by cash as the first choice ($Cash^0$) is 1.24 and 1.55 times, respectively, of that under the uncrowded condition. The unit service time of paying by QR code as the first choice and through only one scanning (QR-Once) under the crowded condition is about 1.14 times of that under the uncrowded condition, not a very large increment. From another point of view, the increment of the unit service time of paying by QR code as the first choice and through only one scanning is 0.39 s, the same with that paying by IC card effectively. The increment of unit service time of paying by cash as the first choice is much longer, about 0.85 s.

5. Conclusions and Suggestions

With the popularization of mobile payment in our daily life, the QR code payment method is more and more commonly adopted in paying the transit fares. This research investigated the service efficiency of the emerging QR code payment method and studied its influence on bus BST, through a set of regression models. The crowdedness was used to determine the regime of the boarding process, and we examined the influence of three main factors of the QR code payment method, i.e., response time, failure in QR code reading, and delay in calling out QR code, on BST under different scenarios. The conclusions can be summarized from the results of the proposed models.

From the perspective of service efficiency, the QR code is lower than cash and IC card. The unit service time of paying by QR code is about two times under the uncrowded condition and 1.5 times under the crowded condition of that paying by cash or IC card, which indicates that the average BST increases a lot under the new hybrid fare collection system.

From the perspective of influence mechanism, the failure in QR code recognition influences the BST by two aspects: first, if passengers insist on paying by the QR code, it needs an extra 1.20 s under the uncrowded condition and 1.42 s under the crowded condition for scanning the QR code again or more times until the paying succeeds; second, if they give up paying by the QR code and transfer to cash, it will cost 5.18 s under the uncrowded condition and 9.49 s under the crowded condition. The delay in calling out QR code is only significant under the uncrowded condition, and every

time it contributes nearly 2 s to the BST. The reason is probably that the uncrowded condition often coincides with the nonpeak periods, and the number of waiting passengers is small so that there is no or a short queue for boarding, leaving less spare time for passengers to call out the QR code in advance before stepping on the vehicle.

Finally, we came up with several suggestions correspondingly, to help transit operators and QR code providers to improve the QR code payment efficiency in the bus transit system.

First, simplifying the step of calling out the QR code, as the percentage of delay in calling out QR code can be as high as 33% in our survey. This delay will prolong the BST by around 2 s under the uncrowded condition. Normally, a boarding passenger needs to wake up the phone, open the payment app, press the payment mark, and choose the e-pass QR code, which is quite complex and time-consuming; therefore, the simplification of calling out the QR code will help to reduce the BST at stops.

Second, improving the recognition accuracy of the QR code, as the failure rate can be as high as 20% according to our survey results. Passengers who failed in paying by QR code as their first choice need an extra 1.20 s–1.42 s to scan the QR code again or several more times until the payment successes. Worse still, if she/he gives up paying by QR code and transfers to cash, it costs as long as 5.18 s under the uncrowded condition and 9.49 s under the crowded condition. Note that the crowded condition is often occurring at peak hours and any delay may lead to a disruption of the service plan.

Last but not least, the response efficiency of the QR code should be enhanced, as the BST per passenger of the QR code almost doubled under the uncrowded condition and 1.5 times under the crowded condition, compared with that of the conventional IC card and cash payment methods.

The transit operators should also pay attention to the slack time plan for incorporating the increments in the bus turnover time. Also, the concerned transit departments should check whether the capacities of bus stops are sufficient to cooperate with the increase of the BST.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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