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# REDUCING PERCEIVED URBAN RAIL TRANSFER TIME WITH ORDINAL LOGISTIC REGRESSIONS

## ABSTRACT

*In order to improve the transfers inside an Urban Rail Transit (URT) station between different rail transit lines, this research newly develops two Ordinal Logistic Regression (OLR) models to explore effective ways for saving the Perceived Transfer Time (PTT) of URT passengers, taking into account the difficulty of improving the transfer infrastructure. It is validated that the new OLR models are able to rationally explain probabilistically the correlations between PTT and its determinants. Moreover, the modelling analyses in this work have found that PTT will be effectively decreased if the severe transfer walking congestion is released to be acceptable. Furthermore, the congestion on the platform should be completely eliminated for the evident reduction of PTT. In addition, decreasing the actual transfer waiting time of the URT passengers to less than 5 minutes will obviously decrease PTT.*

## KEY WORDS

*perceived transfer time; perceived transfer waiting time; ordinal logistic regression model; urban rail transit service improvement;*

## 1. INTRODUCTION

Frequent car usage not only increases the detrimental effect on the environment [1-3] but also makes car users involved in higher risks of traffic accidents especially in the developing countries [4, 5]. Facing up to more and more serious traffic problems caused by frequent car usage, people are increasingly aware of the importance of changing their travel behaviour from excessively depending on cars to mainly using public travel modes [2, 6]. Though taking negative effect on the automotive industry which is, to some extent, important in national economy [7], such changes are encouraged by official policies [8, 9]. However, many people still prefer to utilise private cars in priority, mainly due to unsatisfactory transfers between public transit routes. It has been proven that the passengers will not be satisfied with public transport services they receive until their travel time reductions are commonly deemed worthy of the transfers they made [10-13]. In other words, convenient transfers at interchange stations are critical to successfully improving the public transport services [12, 14, 15] by saving adequate travel time of the passengers [13, 16]. Only in this way can it be possible for more people to abandon the use of private cars, in consideration of their negative attitudes towards making the transfers [14, 17]. Therefore, substantially improving the transfer efficiency plays the key role in both enhancing public transport utilisation and encouraging travel mode redistribution [11, 18].

Nevertheless, various costs for the alterations or reconstructions of the transfer facilities which are ordinarily huge and immovable [19] are too big for Urban Rail Transit (URT) interchange stations which are, to a certain degree, the most important public transport infrastructures, especially in a big city and usually constructed underground. As a result, it will be very difficult for a URT station to objectively reduce the time costs of its users for their transfers between different URT lines inside the station after putting the station into operation. By contrast, reducing the negative influences upon the Perceived Transfer Time (PTT) of the passengers is a practicable and effective way to improve the transfer service inside a URT station. To this end, in view of the difference between the time consumed in reality and the perceived time cost [20], different effects of various factors on the perceived time costs for urban rail transfers have to be analysed in advance.

Generally overestimated [21] and mainly affected by personal attributes of trip-makers (i.e. age, gender, income, and so on) as well as trip-related factors (i.e. total travel time, transfers, travel time period, waiting time, etc.) [22], the perceived time consumptions for travels have been studied for a long time. However, specific analyses on the perceptions of various time costs expensed in public transports are relatively fewer [23] but interesting. For instance, González et al. [23] found that the perceived travel time in tram is a function of both the commuter characteristics and the time consumed in other travel stages. Fan et al. [24] conducted a passenger survey and recorded the waiting passengers at different transit stops in videos to compare the perceived and actual waiting time, and discover that basic amenities at transit stops obviously reduce the perceived waiting time. Moreover, smartphone tracking was used by Delclòs-Alió et al. [22] to analyse the differences between the perceived and the objective time of the daily commutes to a suburban university campus, and the total time spent on the entire commute route has been found as the main variable affecting the differences.

In the relatively fewer but interesting works on the perceived time costs of the public transport passengers, studies on the perceived time consumed in transfers between different URT lines inside a URT station are particularly inadequate. The vague characteristic of the transfer time costs perceived by the URT passengers makes PTT of different passengers with various personal and travel attributes ordinarily evaluated with diverse time cost ranges, which increases the complexity of clarifying the correlations between PTT and its determinant factors. The values of not only PTT but also many of its influencing factors need to be discretized before the quantificational analysis of their correlations. Therefore, owing to its relative superiority in rationally interpreting the relationships between the discrete values of different variables, the Ordinal Logistic Regression (OLR) [25, 26] is utilised in this research to analyse the effect of different actions on reducing PTT of the URT passengers for the urban rail transfer service improvement.

The latter parts of this paper are organised as follows. The survey on the time costs for the urban rail transfers in Beijing is introduced in Section 2, and the survey data are analysed in this part. Thereafter, Section 3 develops two OLR models to interpret the cumulative probabilities of the PTT and the Perceived Transfer Waiting Time (PTWT), respectively. These two newly developed OLR models are applied in Section 4 to predict the probabilistic changes of PTT for different scenarios taking various actions for the improvement of the urban rail transfer service. Finally, Section 5 provides conclusions, suggests ways to reduce PTT of the URT passengers, and discusses some future research issues.

## 2. DATA SURVEY

The survey on PTT of the URT passengers was carried out from November 29th, 2017 to December 5th, 2017, at four locations (i.e. Xizhimen Capita Mall, Zhonguancun Plaza Shopping Mall, Xidan Joy City and Xihongmen LIVAT Shopping Centre) which are next to each of four metro stations in Beijing, respectively. Questionnaires were handed to people staying in the rest areas of these four locations after getting their permissions and ensuring that they had the urban rail transfer experiences within one week. There are three kinds of questions in the questionnaire. The first kind of questions investigate the age, educational background, occupation and income of the respondent. Moreover, the URT utilisation frequency is also questioned in the first kind of questions, because it is very likely to take effect on the accuracy of PTT, in consideration of its influence upon the travel time perception accuracy of the URT passengers [27]. The second kind of questions require people to describe the details of their latest URT travels, such as travel purpose, travel time period, familiarity with the transfer route and total time cost for their entire trips. The third kind of questions focus on the perceptions of people about the transfers in their latest URT travels, including perceived transfer time consumption, perceived walking distance and perceived waiting time. A total of 490 questionnaires were distributed and collected. There were 467 valid questionnaires obtained finally by removing 33 invalid ones.

It is indicated in *Figure 1* that, with the increase of the actual transfer waiting time, the ratio of the samples with the overestimates decreases continually. Meanwhile, the samples underestimating the transfer waiting time keep increasing. Moreover, if the transfer waiting time in reality is approximately between 3 minutes (min) and 5 min, the passengers are more likely to objectively perceive their transfer waiting time. Similar with the changing trends of the sample ratios of PTWT, the ratios of the samples which overestimate and underestimate the transfer walking time continue to decrease and increase, respectively, with the increase of the actual time spent in walking for transfer, as displayed in *Figure 2*. By contrast, *Figure 3* shows that the ratio of the samples with the overestimates first increase sharply and, thereafter, decrease slowly with the increase of the transfer walking distance in reality. If the actual transfer walking distances are between 50 metres (m) and 200 m, the ratios of the samples overestimating the distances are always over 60%. Totally different to the changing trend of the percentage of the samples overestimating the transfer walking distances, the ratio of the samples which underestimate the transfer walking distances keeps increasing slowly with the increase of the actual walking distance in transfer.
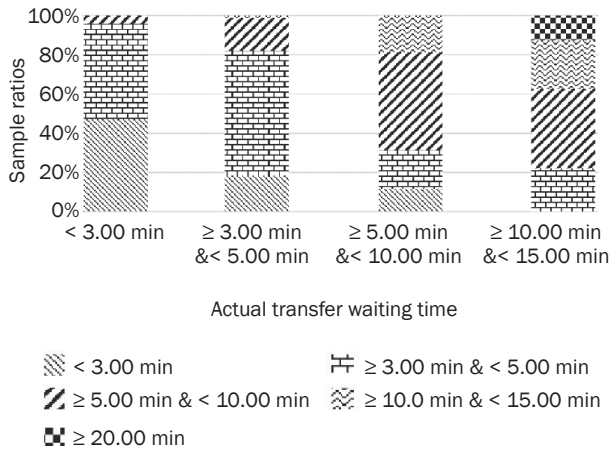
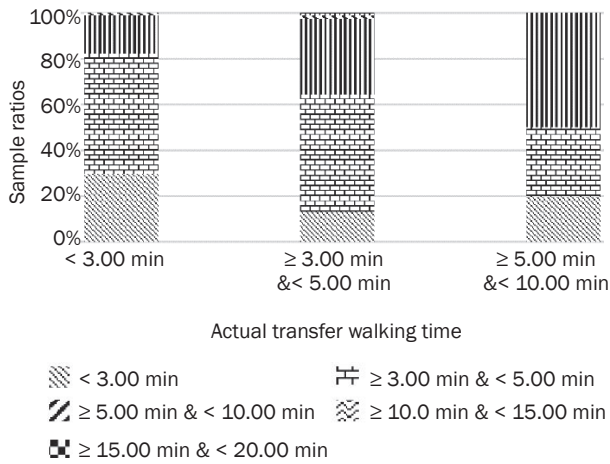*Figure 1 – Sample distribution based on perceived transfer waiting time*



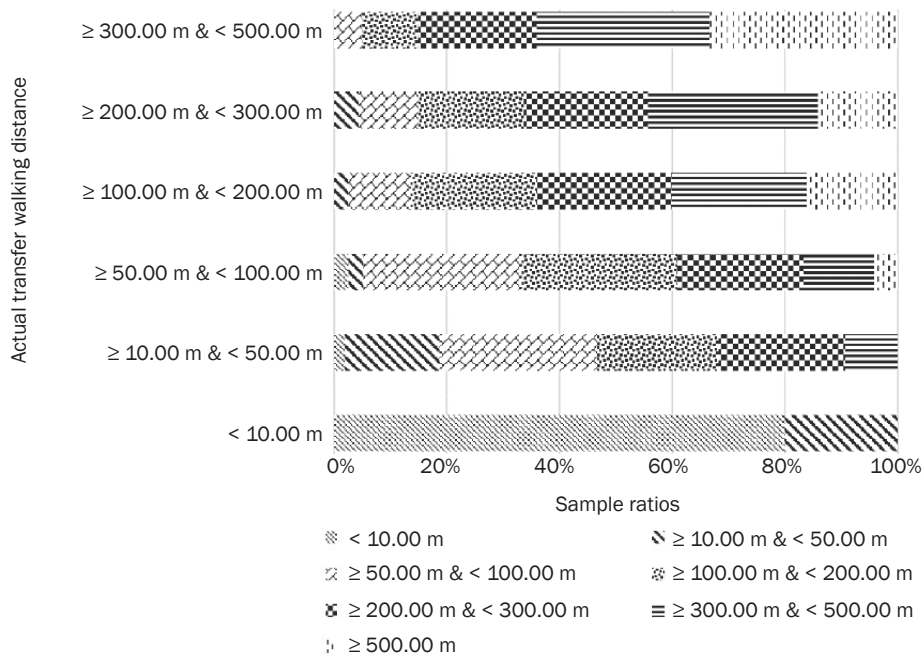*Figure 2 – Sample distribution according to perceived transfer walking time*

## 3. MODELLING STUDY

### 3.1 Model establishments

Based on the sample survey in Beijing, two OLR models for PTT and PTWT have been developed, respectively. The effect of each factor investigated in the survey on PTT and PTWT is tested in the modelling work. The influencing variables of the finally established OLR models only include the effective factors. As explained by *Equation 1*, an OLR model is first established to interpret the relationship between the cumulative classification probability of PTT and the correlated variables. Moreover, as one of the most important factors of PTT, the PTWT classified in this research is also probabilistically explained by its related variables in *Equation 2*. These two OLR models work in cooperation to explain the changes of PTT and explore the effective ways of reducing PTT of the passengers for the urban rail transfer service improvement.

$$
\ln\left(\frac{\gamma_i^{TrT}}{1-\gamma_i^{TrT}}\right) = \alpha_i^{TrT} - 
\begin{Bmatrix}
\beta^{Ge^r} \cdot Ge^r + \sum_{j=1}^{n^{EnT}-1} \beta_j^{T-En^P} \cdot T_j^{En^P} + \beta^{T-Wk^P} \cdot T^{Wk^P} \\
+ \sum_{j=1}^{n^{WkD}-1} \beta_j^{D-Wk^r} \cdot D_j^{Wk^r} + \sum_{j=1}^{n^{WtT}-1} \beta_j^{T-Wt^P} \cdot T_j^{Wt^P} + \sum_{j=1}^{n^{St}-1} \beta_j^{St^r} \cdot St_j^r \\
\beta^{Co-Wk^P} \cdot Co^{Wk^P} + \sum_{j=1}^{n^{WtT}-1} \beta_j^{WW} \cdot T_j^{Wt^P} \cdot T^{Wk^P} + \sum_{j=1}^{n^{St}-1} \beta_j^{SC} \cdot St_j^r \cdot Co^{Wk^P}
\end{Bmatrix} + \varepsilon^{TrT}
\tag{1}
$$

where:

$\gamma_i^{TrT}$ - cumulative probability of all the PTT costs belonging to the classes no bigger than Class $i$;

$\alpha_i^{TrT}$ - constant term for all the PTT costs belonging to the classes no bigger than Class $i$;



*Figure 3 – Sample distribution on the basis of perceived transfer walking distances*

$Ge^r$ — 0-1 variable denoting that the gender of a passenger making a transfer is male (i.e. 1) or female (i.e. 0);

$T_j^{En^p}$ — 0-1 variable representing if the perceived time consumption for an entire trip is at Level $j$ (i.e. 1) or not (i.e. 0);

$n^{EnT}$ — number of all the levels for the perceived time costs of entire trips;

$T^{Wk^p}$ — categorical variable explaining various perceived transfer walking times;

$D_j^{Wk^r}$ — 0-1 variable which denotes if the actual transfer walking distance is at Level $j$ (i.e. 1) or not (i.e. 0);

$n^{WkD}$ — number of all the levels for the transfer walking distances in reality;

$T_j^{Wt^P}$ — 0-1 variable indicating whether the PTWT is at Level $j$ (i.e. 1) or not (i.e. 0);

$n^{WtT}$ — number of all the levels for the PTWT;

$St_j^r$ — 0-1 variable denoting if the quantity of all the stairs utilised in a transfer is at Level $j$ (i.e. 1) or not (i.e. 0);

$n^{St}$ — number of all the levels for the quantities of the utilised stairs;

$Co^{Wk^p}$ — categorical variable interpreting different perceived congestion degrees for walking in a transfer, and

$+\varepsilon^{TrT}$ — error term for the cumulative probability of the PTT. It is assumed in this research that $+\varepsilon^{TrT}$ follows the distribution of $N(0,\sigma_1^2)$.

$$\ln\left(\frac{\gamma_k^{WtT}}{1-\gamma_k^{WtT}}\right) = \alpha_k^{WtT} - \left[\begin{array}{l} \theta^{T\text{-}Wk^p}\cdot T^{Wk^p}\sum_{j=1}^{n^{WkD}-1}\theta_j^{D\text{-}Wk^r}\cdot D_j^{Wk^r} + \theta^{T\text{-}Wt^r}\cdot T^{Wt^r} \\ + \sum_{j=1}^{n^{PtCo}-1}\theta_j^{Co\text{-}Pt^p}\cdot Co_j^{Pt^p} + \theta^{WW}\cdot T^{Wk^p}\cdot T^{Wt^r} \end{array}\right] + \varepsilon^{WtT} \quad (2)$$

where,

$\gamma_k^{WtT}$ — cumulative probability of all the PTWT costs belonging to the classes no bigger than Class $k$;

$\alpha_k^{WtT}$ — constant term for all the PTWT costs which belong to the classes no bigger than Class $k$;

$T^{Wt^r}$ — categorical variable interpreting different actual transfer waiting times;

$Co_j^{Pt^p}$ — 0-1 variable indicating whether the perceived congestion degree on the platform for boarding a train is at Level $j$ (i.e. 1) or not (i.e. 0), and

$\varepsilon^{WtT}$ — error term for the cumulative probability of the PTWT. In this study, the distribution of $\varepsilon^{WtT}$ is hypothesized to follow $N(0,\sigma_2^2)$.

Various value ranges of both PTT and PTWT are interpreted in *Table 1* for their different classes in this work. Moreover, *Table 2* explains the corresponding conditions of different levels for the 0-1 variables in *Equations 1* and *2*. In addition, all the values of the categorical variables in the two newly developed models are interpreted in *Table 3* for their different conditions

*Table 1 – Conditions of different classifications for PTT and PTWT (Unit: min)*

| Probability variable | Corresponding variable | Class 1 | Class 2 | Class 3 | Class 4 |
|---|---|---|---|---|---|
| $\gamma_i^{TrT}$ | PTT | (0.00, 5.00) | [5.00, 10.00) | [10.00, 15.00) | (15.00, +∞) |
| $\gamma_k^{WtT}$ | PTWT | (0.00, 3.00) | [3.00, 5.00) | (5.00, +∞) | - |

*Table 2 – Conditions of different levels for 0-1 variables*

| 0-1 variable | Level basis | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|---|
| $T_j^{En^p}$ | Perceived entire trip time [h] | (0.00, 1.00) | [1.00, 2.00) | [2.00, +∞) | - |
| $D_j^{Wk^r}$ | Actual transfer walking distance [m] | (0.00, 100.00) | [100.00, 200.00) | [200.00, 300.00) | (300.00, +∞) |
| $T_j^{Wt^p}$ | PTWT [min] | (0.00, 3.00) | [3.00, 5.00) | [5.00, +∞) | - |
| $St_j^r$ | Quantity of utilised stairs in a transfer | 0 or 1 | 2 or 3 | 4 or more | - |
| $Co_j^{Pt^p}$ | Perceived platform congestion degree | D1 | D2 | D3 | - |

*Table 3 – Conditions of different values for the categorical variables*

| Categorical variable | Value basis | Value 1.00 | Value 2.00 | Value 3.00 | Value 4.00 |
|---|---|---|---|---|---|
| $T^{Wk^p}$ | Perceived transfer walking time [min] | (0.00, 3.00) | [3.00, 5.00) | [5.00, 10.00) | (10.00, +∞) |
| $Co^{Wk^p}$ | Perceived walking congestion degree | D1 | D2 | D3 | - |
| $T^{Wt^r}$ | Actual transfer waiting time [min] | (0.00, 3.00) | [3.00, 5.00) | [5.00, +∞) | - |

in correspondence. In *Tables 2* and *3*, D1 means that the congestion does not exist, D2 represents that there is acceptable congestion and D3 denotes that the congestion is serious.

## 3.2 Model calibrations

The newly established two OLR models are calibrated according to the maximum likelihood estimation [28]. As shown in *Tables 4* and *5*, the calibration results of both these two OLR models are acceptable from the perspective of statistics. Moreover, with the respective significances of 0.95 and 0.21, they have also satisfyingly passed their Parallel Line tests [25]. Based on the calibration results for *Equation 1*, the Odds Ratio (OR) [25, 26] of $Ge^r$ (i.e. $\exp\left(\beta^{Ge^r}\right)$ which is approximately 0.58) indicates that the PTT costs of the male passengers are ordinarily less than those of the female ones for the same actual transfer time consumptions. The OR of $T_1^{En^p}$ (i.e. $\exp\left(\beta_1^{T-En^p}\right)$ which is about 0.31) means that, in comparison to the passengers with very long perceived time for their entire trips, the passengers who think that less time is spent

*Table 4 – Calibration of Equation 1*

| Parameter | Estimated value | Standard deviation | Wald | Sig. | 95% Confidence interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower limit | Upper limit |
| $\alpha_1^{TrT}$ | -0.40 | 1.20 | 0.11 | 0.74 | -2.75 | 1.96 |
| $\alpha_2^{TrT}$ | 2.57 | 1.21 | 4.54 | 0.03 | 0.21 | 4.94 |
| $\alpha_3^{TrT}$ | 5.14 | 1.24 | 17.18 | 0.00 | 2.71 | 7.57 |
| $\beta^{Ge^r}$ | -0.54 | 0.19 | 7.64 | 0.01 | -0.92 | -0.16 |
| $\beta_1^{T-En^p}$ | -1.16 | 0.50 | 5.27 | 0.02 | -2.14 | -0.17 |
| $\beta_2^{T-En^p}$ | -0.77 | 0.50 | 2.36 | 0.12 | -1.76 | 0.21 |
| $\beta^{T-Wk^p}$ | 0.77 | 0.33 | 5.31 | 0.02 | 0.11 | 1.42 |
| $\beta_1^{D-Wk^r}$ | -1.10 | 0.46 | 5.86 | 0.02 | -1.99 | -0.21 |
| $\beta_2^{D-Wk^r}$ | -0.95 | 0.44 | 4.75 | 0.03 | -1.80 | -0.10 |
| $\beta_3^{D-Wk^r}$ | -0.25 | 0.43 | 0.34 | 0.56 | -1.08 | 0.59 |
| $\beta_1^{D-Wt^p}$ | 2.59 | 1.04 | 6.24 | 0.01 | 0.56 | 4.62 |
| $\beta_2^{D-Wt^p}$ | 2.93 | 0.79 | 13.75 | 0.00 | 1.38 | 4.48 |
| $\beta_1^{St^r}$ | 0.82 | 0.30 | 7.47 | 0.01 | 0.23 | 1.41 |
| $\beta_2^{St^r}$ | -3.48 | 0.91 | 14.73 | 0.00 | -5.26 | -1.71 |
| $\beta^{Co-Wk^p}$ | -2.98 | 0.84 | 12.45 | 0.00 | -4.63 | -1.32 |
| $\beta_1^{WW}$ | 1.23 | 0.40 | 9.30 | 0.00 | 0.44 | 2.02 |
| $\beta_2^{WW}$ | 1.00 | 0.36 | 7.73 | 0.01 | 0.30 | 1.71 |
| $\beta_1^{SC}$ | -0.83 | 0.44 | 3.63 | 0.06 | -1.69 | 0.02 |
| $\beta_2^{SC}$ | -1.00 | 0.33 | 9.20 | 0.00 | -1.65 | -0.35 |

*Table 5 – Calibration of Equation 2*

| Parameter | Estimated value | Standard deviation | Wald | Sig. | 95% Confidence interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower limit | Upper limit |
| $\alpha_1^{WtT}$ | 2.68 | 0.77 | 12.21 | 0.00 | 1.18 | 4.18 |
| $\alpha_2^{WtT}$ | 5.93 | 0.81 | 53.28 | 0.00 | 4.33 | 7.52 |
| $\theta^{T-Wk^p}$ | 1.06 | 0.31 | 11.63 | 0.00 | 0.45 | 1.67 |
| $\theta_1^{D-Wk^r}$ | -0.81 | 0.38 | 4.49 | 0.03 | -1.56 | -0.06 |
| $\theta_2^{D-Wk^r}$ | -0.98 | 0.37 | 6.97 | 0.01 | -1.70 | -0.25 |
| $\theta_3^{D-Wk^r}$ | -0.65 | 0.38 | 2.88 | 0.09 | -1.41 | 0.10 |
| $\theta^{T-Wt^r}$ | 2.70 | 0.44 | 37.18 | 0.00 | 1.84 | 3.57 |
| $\theta_1^{Co-Pt^p}$ | -1.13 | 0.38 | 8.78 | 0.00 | -1.87 | -0.38 |
| $\theta_2^{Co-Pt^p}$ | -0.21 | 0.21 | 1.06 | 0.30 | -0.62 | 0.19 |
| $\theta^{WW}$ | -0.56 | 0.20 | 7.89 | 0.00 | -0.96 | -0.17 |

on their entire trips, usually have relatively short PTT. In addition, the ORs of $D_1^{Wk^r}$ (i.e. $\exp\left(\beta_1^{D\text{-}Wk^r}\right)$ which is around 0.33) and $D_2^{Wk^r}$ (i.e. $\exp\left(\beta_2^{D\text{-}Wk^r}\right)$ which is approximately 0.39) prove that the URT passengers with relatively short actual walking distances in transfers commonly have less PTT.

Furthermore, on the basis of the calibration results shown in *Table 4*, the OR of $T^{Wk^p}$ (i.e. $\exp\left(\beta_1^{WW}\right)$) is about 3.42 when the PTWT is less than 3 min, and its OR (i.e. $\exp\left(\beta_2^{WW}\right)$) is around 2.72 when the PTWT is over 3 min and no more than 5 min. This indicates that more perceived transfer walking time normally makes more PTT especially if less PTWT is consumed, because PTT is comprehensively decided by the successive stages of a transfer. It is also found that, when 2 or 3 stairs are utilised in a transfer, the OR of $Co^{Wk^p}$ (i.e. $\exp\left(\beta_2^{SC}\right)$) is equal to approximately 0.37. This suggests that, as a result of the effect of comprehensive transfer walking environment, the increase of the perceived walking congestion degree always has PTT increased easily if relatively many stairs are utilised in a transfer.

According to the calibration of *Equation 2*, the ORs of $D_1^{Wk^r}$ (i.e. $\exp\left(\theta_1^{D\text{-}Wk^r}\right)$ which is approximately 0.44) and $D_2^{Wk^r}$ (i.e. $\exp\left(\theta_2^{D\text{-}Wk^r}\right)$ which is about 0.38) clarify that PTWT generally decreases slightly at first and, thereafter, increases with increasing the actual transfer walking distance. If the actual transfer walking distance is between 100 m and 200 m, the passengers are more likely to have the least PTWT. Moreover, the OR of $Co_1^{Pt^p}$ (i.e. $\exp\left(\theta_1^{Co\text{-}Pt^p}\right)$ which is around 0.32) indicates that a platform which is not congested makes passengers comfortable, which usually results in relatively short PTWT. In addition, it is also ensured by the

calibrated value of $\theta^{WW}$, shown in *Table 5*, that PTWT is simultaneously determined by the successive stages of a transfer.

## 3.3 Accuracy evaluations

If the predicted classification probability of a PTT cost for a certain class is the biggest in comparison to its predicted probabilities for other classes, the PTT cost is predicted to belong to this class. The surveyed and predicted classes of an accurately predicted sample are the same to each other. In accordance with this principle, the model accuracy is evaluated by *Equation 3*. The surveyed classes of the PTT and PTWT samples in this study and their classes predicted by the newly developed two OLR models are compared in *Tables 6* and *7*, respectively. According to *Equation 3*, the accuracy of the PTT OLR model explained by *Equation 1* is evaluated to be about 62.10% for all the 467 valid samples. Moreover, it is also found that this model is good at predicting the classes of the samples with the surveyed PTT which is at least 5 min and, at the same time, less than 10 min. Its accuracy is around 79.63% for such samples. By comparison, in spite of its a little lower accuracy (i.e. approximately 59.53%) for all the 467 valid samples, the PTWT OLR model interpreted by *Equation 2* is still able to truly predict the classes of PTWT in general. Furthermore, in comparison to the accuracies for other PTWT classes, the best accuracy (i.e. about 67.22%) of the PTWT OLR model is for the samples with PTWT which is at least 3 min but less than 5 min.

$$R_a = \frac{N_a}{N_s} \cdot 100\% \qquad (3)$$

where,

$R_a$ - model accuracy;

$N_a$ - amount of accurately predicted samples, and

$N_s$ - amount of the samples for accuracy evaluation.

*Table 6 – Distribution matrix of predicted and surveyed PTT classes*

| PTT | | Predicted classes | | | | Summary |
|---|---|---|---|---|---|---|
| | | Class 1 | Class 2 | Class 3 | Class 4 | |
| Surveyed classes | Class 1 | 63 | 52 | 0 | 0 | 115 |
| | Class 2 | 23 | 172 | 19 | 2 | 216 |
| | Class 3 | 3 | 51 | 50 | 4 | 108 |
| | Class 4 | 0 | 10 | 13 | 5 | 28 |
| Summary | | 89 | 285 | 82 | 11 | 467 |

*Table 7 – Distribution matrix of predicted and surveyed PTWT classes*

| PTWT | | Predicted classes | | | Summary |
|---|---|---|---|---|---|
| | | Class 1 | Class 2 | Class 3 | |
| Surveyed classes | Class 1 | 100 | 71 | 2 | 173 |
| | Class 2 | 76 | 162 | 3 | 241 |
| | Class 3 | 3 | 34 | 16 | 53 |
| Summary | | 179 | 267 | 21 | 467 |

## 4. SCENARIO ANALYSES

Based on both calibrated OLR models developed in the last Section, three scenarios are studied in this Section to analyse their effect on reducing PTT for the improvements of urban rail transfer services in Beijing, in consideration of the practicalities of different actions. Various actions taken in each of the scenarios are explained as follows.

*Scenario 1*: Release walking congestion. That is, decrease the categorical value of the perceived walking congestion degree of the URT passengers believing that the transfer walking environment is very congested from 3.00 to 2.00 (i.e. Decrease-S1A) and 1.00 (i.e. Decrease-S1B), respectively.

*Scenario 2*: Release waiting congestion. That is, decrease the perceived waiting congestion degree of the passengers regarding that the platform for boarding a train is very congested from Level 3 to Level 2 (i.e. Decrease-S2A) and Level 1 (i.e. Decrease-S2B), respectively.

*Scenario 3*: Decrease the actual transfer waiting time. That is, decrease the categorical value of the actual transfer waiting time which is no less than 5 min from 3.00 to 2.00 (i.e., Decrease-S3A) and 1.00 (i.e., Decrease-S3B), respectively, for the passengers in correspondence.

The effect of different actions on changing the PTT class distribution of the corresponding passengers is shown in *Tables 8-10* for different scenarios, respectively. It is shown in *Table 8* that, if the passengers who perceive that the transfer walking environment is very congested, are successfully convinced that the congestion degree has decreased to an acceptable value, some of them will believe that the time spent for their transfers is reduced from at least 15 min to less than 15 min but at least 10 min. Meanwhile, some of the passengers who deem the transfer walking environment very congested will perceive that their transfer time is decreased from at least 5 min but less than

10 min to less than 5 min. However, at the same time, some of the passengers will believe that their PTT increases from at least 5 min but less than 10 min to at least 10 min but less than 15 min.

If the passengers with the belief of a very congested transfer walking environment perceive that the congestion is disappearing, some of them will confirm that their PTT has been reduced from at least 15 min to less than 15 min but at least 10 min, as shown in *Table 8*. On the contrary, some of the passengers will be sure of the increase of their PTT from at least 5 min but less than 10 min to at least 10 min but less than 15 min. Meanwhile, the passengers with PTT less than 5 min neglect such congestion release. As a result, it is indicated that the release of serious transfer walking congestion to an acceptable degree will effectively reduce PTT of some passengers, in view of lots of difficulties and relatively poor effect of eliminating the transfer walking congestion.

It is found in *Table 9* that, if the URT passengers who are confident that the platform for boarding a train is very congested, perceive that the congestion is becoming acceptable, their PTT has no change. Only if the congestion on the platform disappears, an apparent share of these passengers will believe that their PTT is reduced from at least 5 min but less than 10 min to less than 5 min, though a very minor part of these passengers trust that their PTTs increase from at least 5 min, but less than 10 min to at least 15 min. Therefore, it is confirmed that completely eliminating the congestion on the platform is very important not only for the PTT reductions of the URT passengers but also for their safety.

As explained in *Table 10*, with the decrease of the transfer waiting time in reality from no less than 5 min to at least 3 min, but less than 5 min and, successively, less than 3 min, more and more passengers who believe they spend at least 5 min in waiting for boarding the trains in transfers perceive that their transfer time has been reduced. Especially when the actual

*Table 8 – Class distribution of PTT for Scenario 1*

| Classes | Current distribution [%] | Distribution after Decrease-S1A [%] | Distribution after Decrease-S1B [%] |
|---------|--------------------------|-------------------------------------|-------------------------------------|
| Class 1 | 18.96 | 19.91 | 18.96 |
| Class 2 | 59.72 | 56.87 | 57.35 |
| Class 3 | 17.06 | 21.80 | 20.85 |
| Class 4 | 4.26 | 1.42 | 2.84 |

*Table 9 – Class distribution of PTT for Scenario 2*

| Classes | Current distribution [%] | Distribution after Decrease-S2A [%] | Distribution after Decrease-S2B [%] |
|---------|--------------------------|-------------------------------------|-------------------------------------|
| Class 1 | 18.77 | 18.77 | 21.46 |
| Class 2 | 64.37 | 64.37 | 61.30 |
| Class 3 | 14.18 | 14.18 | 14.18 |
| Class 4 | 2.68 | 2.68 | 3.07 |

*Table 10 – Class distribution of PTT for Scenario 3*

| Classes | Current distribution [%] | Distribution after Decrease-S3A [%] | Distribution after Decrease-S3B [%] |
|---------|--------------------------|-------------------------------------|-------------------------------------|
| Class 1 | 4.00 | 40.00 | 44.00 |
| Class 2 | 88.00 | 60.00 | 56.00 |
| Class 3 | 8.00 | 0.00 | 0.00 |
| Class 4 | 0.00 | 0.00 | 0.00 |

transfer waiting time decreases from at least 5 min to less than 5 min but at least 3 min, a very remarkable share of such passengers think so, in comparison to the effect of decreasing the transfer waiting time in reality from less than 5 min but at least 3 min to less than 3 min. This makes it clear that reducing the waiting time of the passengers for boarding trains on the platforms in transfers to less than 5 min is significant for the decrease of PTT.

According to different impacts of applying various strategies on reducing PTT of the URT passengers, it is apparent that reducing the waiting time of the passengers for boarding the trains on the platforms in transfers to less than 5 min is the most effective one. In the second place, completely eliminating congestion on a platform is very important from the perspectives of both PTT reduction and passenger safety. In addition, releasing the transfer walking congestion to an acceptable level also contributes to the decrease of PTT. Sometimes, even if very frequent train services are provided to make it possible for the URT passengers to have less transfer waiting time, the congestion on the platform makes the passengers have to wait longer before boarding their connection trains. The PTT of the URT passengers will be much increased in such a case. As result, the congestion on the platform is easy to result in a serious increase of PTT and does a big harm to the satisfaction of passengers with the transfer service they receive.

## 5. CONCLUSION

In order to improve the urban rail transfer service, a survey on the PTT of the URT passengers in Beijing has been carried out first. Two OLR models have been accordingly developed to explore the effective ways of reducing PTT of the passengers, in consideration of the difficulty of the URT station infrastructure improvements and the superiority of the OLR analysis in explaining the correlations between variables with discrete values. It has been confirmed that the newly developed models are able to rationally interpret the probabilistic changes of PTT with the values of its determining factors. It is found that PTT of the URT passengers will be effectively decreased as long as the serious congestion during walking in transfer is acceptable. In contrast, eliminating the congestion on the platform is essential to the valid decrease of PTT. Moreover, reducing the actual transfer waiting time of

the passengers on the platform to less than 5 min will obviously decrease PTT. In addition, according to the survey on PTT, providing time information along the transfer routes may reduce PTT as well.

In view of the serious negative influence of the congestion on the platform upon PTT, it is suggested that, in the peak hours of urban rail operations, besides adequately decreasing the headways of the train services, the guidance on the platform needs to be evidently improved to reduce the congestion as much as possible. In contrast, in the non-peak hours, smoothly cooperative arriving and departing time of the trains operating on different rail transit lines is the key for the transfers of passengers to reducing their PTT efficiently. Due to limited human and financial resources, the number of the survey samples about PTT of the URT passengers in Beijing is not large. In future research, more URT passengers in Beijing will be surveyed to validate the results of this research. Moreover, the new OLR models developed in this research also need to be applied to analyse PTT of the URT passengers in different cities in the world to further improve their effectiveness.

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摘要

考虑到城市轨道交通车站换乘设施更新的困难性，为提高城市轨道交通换乘服务的质量，本研究建立了两个新的多项逻辑回归模型，以探求减少城市轨道交通乘客换乘感知时间的有效方法。新建立的多项逻辑回归模型能够从

概率推理的角度，合理地解释城市轨道交通乘客换乘感知时间与其影响因素之间的关系。研究发现在换乘走行过程中，若拥挤程度缓解至换乘乘客可接受，则乘客的换乘感知时间将有效减少。此外，为了切实地减少城市轨道交通乘客换乘感知时间，城市轨道交通车站站台应避免人员拥挤的情况发生。另外，如果能使乘客在其换成过程中的实际等待时间少于五分钟，则乘客的换乘感知时间将明显减少。在未来的研究中，新建立的多项逻辑回归模型仍需应用于不同城市的轨道交通乘客换乘感知时间分析，从而更近进一步地完善研究成果。

关键词

换乘感知时间；换乘等待感知时间；多项逻辑回归模型；城市轨道交通服务提升

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